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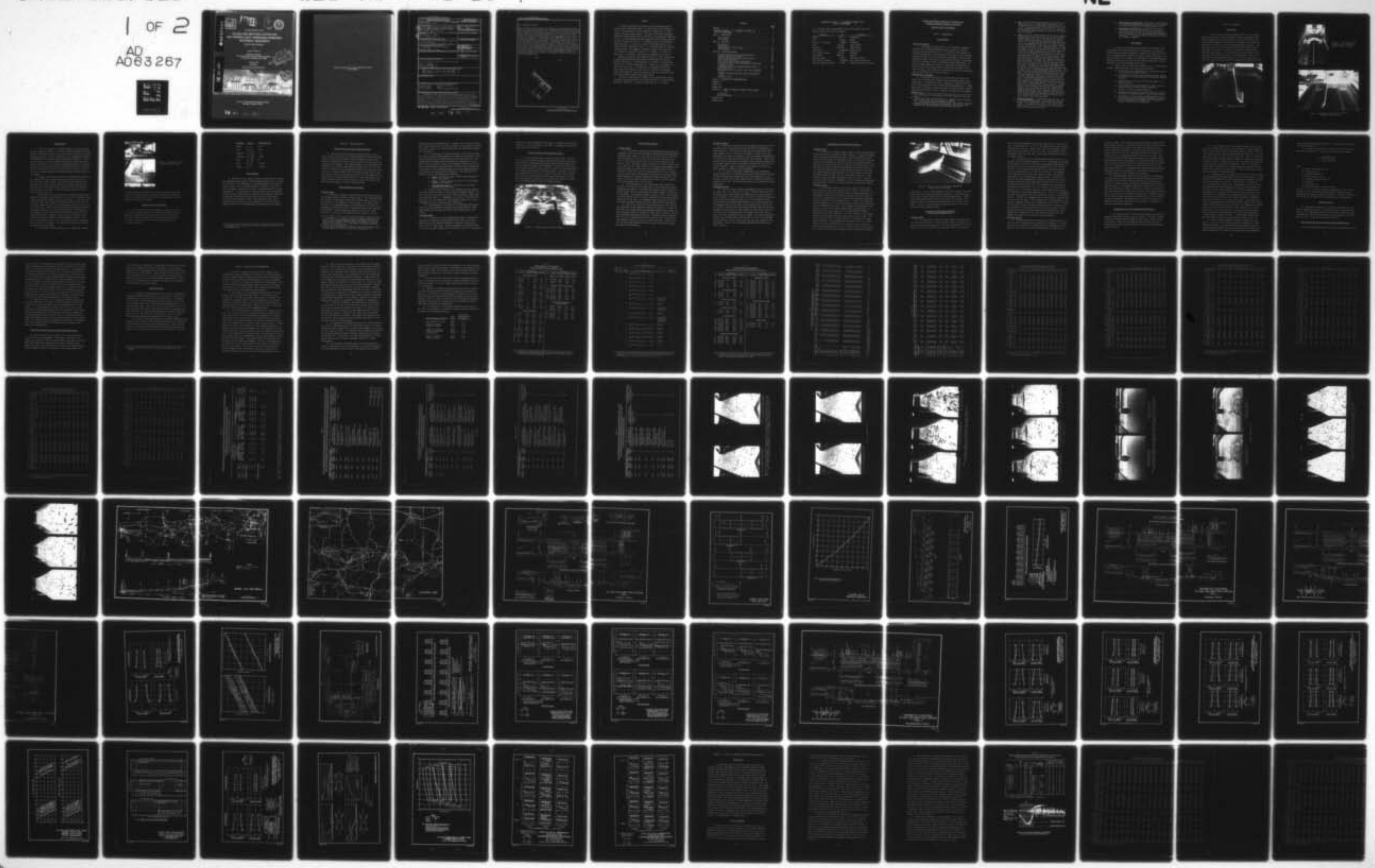

TECHNICAL REPORT H-78-19

FILLING AND EMPTYING SYSTEM FOR BAY SPRINGS LOCK, TENNESSEE-TOMBIGBEE WATERWAY, MISSISSIPPI

Hydraulic Model Investigation

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The hydraulic model investigation reported herein was concerned with planning and design of a single lift, 110- by 600-ft lock (pintle to pintle), at the southern end of the Divide Section of the Tennessee-Tombigbee Waterway. Normally, an 84-ft lift condition will obtain, but a maximum of 92 ft or a minimum of 78 ft is possible at the site. A 1:25-scale model was built to study the filling and emptying system. The system proposed by the Nashville District and developed in the model test was of the longitudinal floor culvert

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type. Culverts in each lock wall are connected to a crossover culvert with a horizontal splitter wall dividing flow to upstream and downstream tuning forks where equal division leads into the two longitudinal floor culverts in each end of the chamber, near the chamber quarter point. With the ~~type~~ T 17 (recommended) design, the model gave filling and emptying times of 10.5 min and 13.3 min, respectively, with a 1-min filling valve and a 2-min emptying valve. The prototype can be expected to fill and empty about 18% ~~percent~~ faster (8.6 min and 10.9 min, respectively). Flow conditions in the lock chamber during filling were excellent with a very small degree of turbulence. Unmoored half tows in the lock chamber either rose vertically or drifted toward the center of the lock, and full tows drifted very slowly toward the lower miter gate during the latter part of the filling operation. Unmoored tows should never be permitted in locks, but this performance indicates built-in safety for this longitudinal floor culvert system. The system developed is particularly desirable for high-lift locks in that it is insensitive to misoperation; ~~that is,~~ dangerous surges in the lock chamber cannot be created by fast operation of the valves, nonsynchronous operation of the valves, or intermittent stopping of the valves during the opening cycle.

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PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers (OCE), on 11 March 1974, at the request of the U. S. Army Engineer District, Nashville, through the U. S. Army Engineer Division, South Atlantic. The model tests were accomplished during the period November 1974 to May 1976 in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of Structures Division, and under the direct supervision of Mr. G. A. Pickering, Chief of Locks and Conduits Branch. The engineer in immediate charge of the model was J. H. Ables, Jr., assisted by Messrs. H. O. Turner, C. L. Dent, H. H. Allen, and J. O. McLaurin. This report was prepared by Mr. Ables.

Messrs. Sam Powell, Bruce McCartney, and J. P. Davis (Consultant) of OCE; William McCormick, Bert Holler, and Ted Abeln of the South Atlantic Division; R. C. Armstrong and W. H. Browne of the Ohio River Division; E. C. Moore, Herman Gray, R. J. Conner, H. F. Phillips, T. M. Allen, Bill Gray, and J. T. Hoffmeister of the Nashville District; Wayne Odom of the Mobile District; and T. E. Murphy, HL Consultant, visited WES during the course of the model study to observe model operation and correlate results with design studies.

Directors of WES during the conduct of the investigation and the preparation and publication of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
acres	4046.856	square metres
acre-feet	1233.482	cubic metres
square feet	0.09290304	square metres
tons (2000 lb, mass)	907.185	kilograms
tons (force)	8896.444	newtons
feet per second	0.3048	metres per second
cubic feet per second	0.02831685	cubic metres per second
feet per second per second	0.3048	metres per second per second

FILLING AND EMPTYING SYSTEM FOR BAY SPRINGS LOCK
TENNESSEE-TOMBIGBEE WATERWAY, MISSISSIPPI

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

Location of project

1. Bay Springs Lock and Dam will be the uppermost navigation structure on the Tennessee-Tombigbee Waterway above the existing Demopolis Lock and Dam (Plate 1). It is located at the southern end of the Divide Section of the waterway and will create a pool extending through the Divide Cut to the Yellow Creek embayment of Pickwick Lake (Tennessee River). The site for the Bay Springs Project is on Mackeys Creek in the southwest corner of Tishomingo County, Mississippi. At el 414,* normal summer pool level, the impoundment exclusive of the Divide Cut will have 6,700 acres** of surface area and 180,000 acre-feet of storage. The location of Bay Springs Lock and Dam, Bay Springs Lake, and the Divide Cut is shown in Plate 2.

Description of structures

2. The principal structures for the Bay Springs Project will consist of a rock-fill dam, navigation lock, downstream channel, and saddle dikes. A spillway will not be required, as explained in detail in the hydrology portion of the General Design Memorandum N-11.† Saddle dikes will be provided at locations around the reservoir where existing ground levels are below el 449 to contain the Tennessee River probable maximum flood.

* All elevations (el) cited herein are in feet referred to mean sea level.

** A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

† U. S. Army Engineer District, Nashville, CE, "Bay Springs, Tennessee-Tombigbee Waterway, Mississippi and Alabama," General Design Memorandum N-11, with Supplement, May 1975, Nashville, Tenn.

a. Dam. The rock-fill dam with impervious core will be approximately 120 ft in height above the Mackeys Creek streambed and will be approximately 2800 ft long at the crest. The upstream slope of the dam will be 1V on 2.5H and the downstream slope will be 1V on 2.0H. Upstream and downstream berms of random rock fill will be provided west of the lock.

b. Lock. The lock, located near the left end of the dam and perpendicular to the axis of the dam, will have nominal chamber dimensions of 110 ft wide by 600 ft long, with 670 ft between center lines of the miter gate pintles (Plate 3). The upstream and downstream right guide walls will be approximately 600 and 550 ft in length, respectively. Two monoliths of the upper guide wall, located just upstream from the culvert intake manifold, will have openings 20 ft wide by 47 ft high with inverts at el 352 to provide a means of lowering the pool water level from the top of the water-quality control dike, el 384, to el 352 in case drawdown of the reservoir is required for maintenance work on the dam or for other reasons. Steel wall armor will be placed on exposed faces of the lock walls at locations susceptible to damage from barge impact and rubbing. The upper sill will have a top elevation of 393 and will act as a seal for the upper miter gate and as a support for the upstream emergency closure stop logs. The lower sill will have a top elevation of 315 and will act as the seal for the lower miter gate and as support for the downstream maintenance stop logs. Upper and lower gates will be horizontally framed miter type gates. The lock filling and emptying system will consist of intake manifolds located in the chamber side of each lock wall immediately upstream of the upper miter gate sill; a 14-ft-square longitudinal culvert in each lock wall; a system of longitudinal floor culverts within the lock chamber; and a discharge diffuser system that will empty into the downstream channel. Flow in the culverts will be controlled by reverse tainter valves. A control station will be located on the left wall approximately midway of the lock chamber to house the electrical distribution switchboard, control console, standby diesel engine generator unit, water treatment plant, and other electrical and mechanical equipment for operation of the lock. Control booths will be located on the left wall near the upper and lower miter gates.

c. Downstream channel. The portion of the canal for a distance of approximately 2800 ft downstream from the axis of dam will be constructed as part of the Bay Springs Project. The channel width will be 300 ft and the side slopes will be 4V on 1H in rock and 1V on 3H in earth, with a 10-ft berm at top of rock.

d. Flood protection structures. Construction of saddle dikes at six locations around Bay Springs Lake will be required to contain the Tennessee River probable maximum flood.

e. Water-quality control weir. A rock-fill weir, with a 10-ft crest at el 384 and slopes of 1V on 3H, will be constructed across the upper lock approach perpendicular to the right guide wall so that desired water temperature releases to the Lock E pool will be realized each time the lock chamber is emptied.

The Problems

3. A model testing program was essential for the design of Bay Springs Lock since the prime objective of the project is to provide safe, reliable, and rapid navigation. Because of the high lifts (78 to 92 ft) involved, model studies were needed to ensure the adequacy of the various elements of the system; to ensure that no undesirable hydraulic conditions exist; and to ensure that the proposed system will provide a safe means for filling and emptying the lock.

4. Results from the model tests needed by the U. S. Army Engineer District, Nashville (ORN), for design purposes included:

a. Verification of the effectiveness of the proposed design of the filling and emptying system.

b. Determination of conditions in the upper approach during filling and in the lower approach and canal when emptying the lock.

c. Evaluation of the effects of raising the intakes to a higher elevation.

d. Flow conditions and characteristics of tows in the lock chamber during filling and emptying operations.

e. Location of the lock emptying manifolds.

f. Determination of hydraulic conditions when lock culverts are used for emergency drawdown of Bay Springs Reservoir.

g. Determination of water-surface differentials across the miter gates during normal filling and emptying operations and the necessity for programmed valves to prevent excessive overfilling and overemptying.

PART II: THE MODEL

Description

5. The 1:25-scale lock model reproduced 700 ft of the upstream approach, the entire filling and emptying system including the upper guide and guard walls, intakes (Figure 1), valves and culverts, floor culvert system (Figure 2), outlets, the lock chamber, lower guide and guard walls, and about 600 ft of downstream approach (Figure 3). The approach areas and the lock chamber were constructed of plywood and the intakes, valve wells, culverts, and outlets were constructed of sheet metal and plastic. The culvert valves were constructed of sheet metal and fitted with rubber seals to prevent leakage. Eight sheet-metal barges, each simulating a length of 140 ft and a width of 50 ft (Plate 4), were loaded with weights to reproduce the desired 9-ft draft.

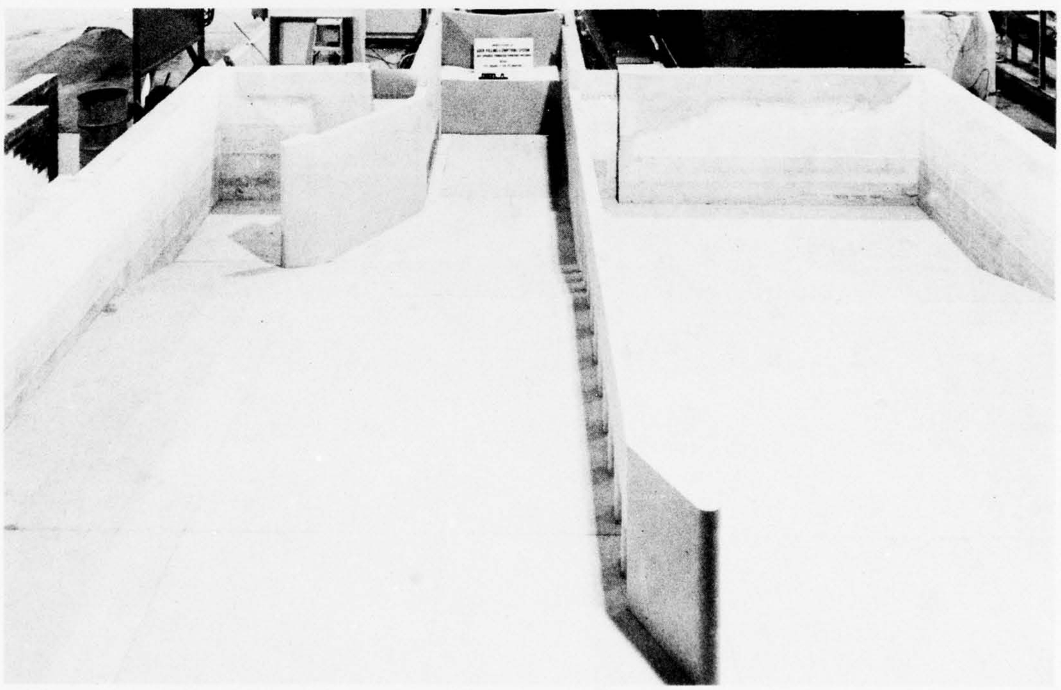

Figure 1. Upstream lock approach

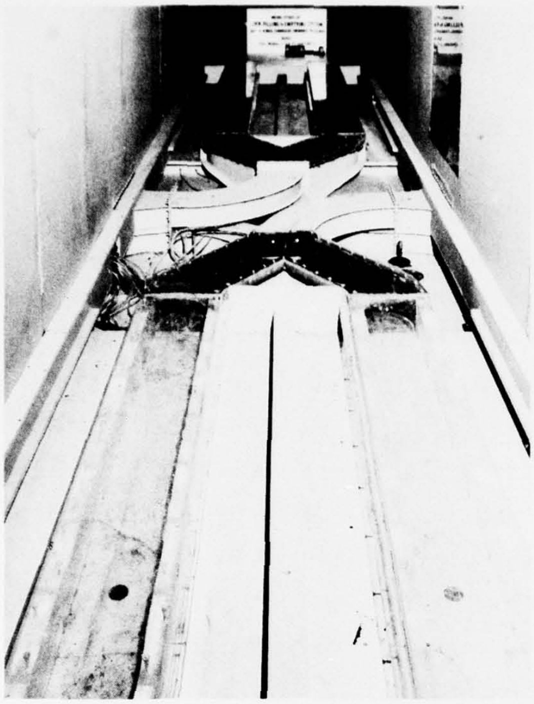

Figure 2. Longitudinal floor culverts, type 1 (original) design, looking downstream

Figure 3. Downstream lock approach and type 1 (original) design outlets

Appurtenances

6. Water was supplied to the model through a circulating system. Both the headbay and tailbay of the model contained skimming weirs that maintained essentially constant upper and lower pools during filling and emptying operations. Vertical adjustments of the skimming weirs permitted simulation of any desired upper and lower pool elevations. Dye and confetti were used to study subsurface and surface current directions. Pressure cells were used to measure instantaneous pressures at selected locations in the culvert system and to record water surface in the lock chamber. Differential pressure cells were used to record the difference in lock chamber water-surface elevation between selected points in the chamber.

7. By means of the linear motion of a gear-rack-driven cam plate, the culvert-valve drive mechanism accurately controlled the rate at which the tainter valves opened. The gear drive was powered by a reversible motor. Limit switches mounted on the gear-rack guide automatically shut off the valve drivers when either the fully opened or closed position was reached. The valve opening schedule used in the tests is shown in Plate 5.

8. Hawser-pull (force links) devices for determining the longitudinal and transverse forces acting on a tow in the lock chamber during filling and emptying operations are shown in Figure 4. Three such devices were used: one to measure longitudinal forces and the other two to measure transverse forces on the downstream and upstream ends of the tow, respectively. These links were machined from aluminum and had SR-4 strain gages cemented to the inner and outer edges. When the device was mounted on the tow, one end of the link was pin-connected to the tow while the other end engaged a fixed vertical rod and was free to move up and down with changes in the water-surface elevation in the lock. Any horizontal motion of the tow caused the links to deform and vary the signal to a recorder. The links were calibrated by inducing deflection with known weights.

9. All data were recorded graphically on a commercial recorder.

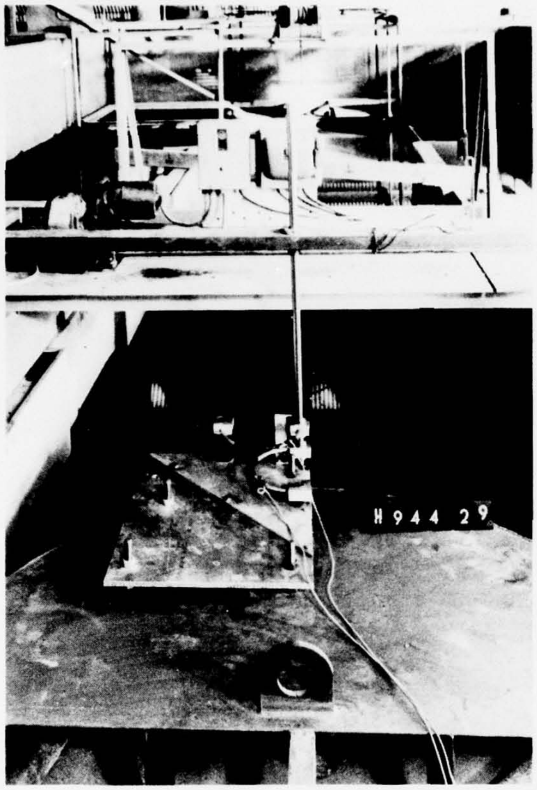

Figure 4. Hawser-pull (force links) measuring device

The sensing elements (mechanical to electrical conversion devices) located at various points on the model were connected by shielded cables to amplifiers where the outputs were stepped up to the level required for graphical recording.

Interpretation of Test Results

10. The accepted equations of hydraulic similitude, based on the Froudian relations, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for the transfer of the model data to prototype equivalents, or vice versa, are presented in the following tabulation:

Dimension	Ratio	Scale Relations
Length	$L_r = L$	1:25
Area	$A_r = L_r^2$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3125
Time	$T_r = L_r^{1/2}$	1:5
Force	$F_r = L_r^3$	1:15,625
Weight	$W_r = L_r^3$	1:15,625

Test Procedure

11. Evaluation of the various elements of the system was based on data obtained during typical filling and emptying operations at a normal 84-ft lift and 15-ft submergence.* Performance primarily was based on hawser forces on tows in lockage, movement of unmoored (free) tows in the lock chamber, turbulence, pressures, and time required for filling and emptying. In determination of flow distribution and some pressure conditions, and in some studies of approach flow conditions, fixed-head (steady flow) conditions were used with the culvert valves and/or miter gates fully opened or closed. For steady-flow tests, water-surface elevations within the lock chamber were set from filling or emptying curves for the corresponding initial head and valve opening.

* Submergence is the difference in elevation between lower pool and the lock chamber floor.

PART III: TESTS AND RESULTS

Original Design Filling and Emptying System

12. The original design filling and emptying system, shown in Plate 3, was very similar to the adopted Bankhead Lock filling and emptying system that was developed in previous hydraulic model investigations.* Modification of the crossover culverts and outlets were the principal design changes. The primary elements of the Bay Springs system consists of 10-port intake manifolds leading to 14- by 14-ft culverts in each wall; filling and emptying valves of the same size as the culverts; a crossover culvert with a horizontal splitter wall in each main culvert to divide flows into each half of the lock chamber in conjunction with two tuning forks leading to the four longitudinal floor culvert manifolds; and six outlet culverts to spread flow between the lock walls and outside of the guide and guard walls.

Upstream Approach and Intakes

Original design

13. The type 1 (original) intake manifold, guide and guard walls, and upstream approach are shown in Plates 3 and 6. The intake manifolds were designed in accordance with EM 1110-2-1604,** using a value of 1.8 for the ratio of the summation of throat widths to the culvert width. The roof of the intake manifolds at el 366 provided 42 ft and 48 ft of submergence, respectively, below the minimum and normal pool elevations of 408 and 414. Under steady-flow conditions, there was a slight deficiency of flow in the four downstream ports (Plate 7), but the

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* N. R. Oswalt, J. H. Ables, Jr., and T. E. Murphy, "Navigation Conditions and Filling and Emptying System, New Bankhead Lock, Black Warrior River, Alabama; Hydraulic Model Investigation," Technical Report H-72-6, Sep 1972, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

** Office, Chief of Engineers, "Hydraulic Design of Navigation Locks," Engineer Manual EM 1110-2-1604, Apr 1963, Washington, D. C.

distribution was considered adequate. Pressures in the intake and original design filling system are listed in Table 1 and piezometer locations are shown in Plate 8. No vortexes formed over the intake during steady-flow observations.

14. Flow conditions in the upper approach to the lock and intake were studied during filling operations to ensure that conditions in this area would permit safe entrance and exit of tows and small craft. The limited width of approach that can normally be reproduced in a lock model confines the area of study to the immediate vicinity of the lock. Surface and subsurface current patterns in this area were observed, and the tendency for vortex formation above the culvert intakes provides a good reference for evaluating flow conditions. The following terminology is used in describing vortex tendencies.

- a. Swirl. A vortex with only a slight concave depression in the water surface.
- b. Vortex. A vortex with an air cavity or tail extending below the water surface.
- c. Air-entraining vortex. A vortex with an air cavity extending into the culvert.

15. Surface current patterns in the immediate upstream approach area were recorded by means of 5-sec exposure photographs taken at 1.5, 4.0, 6.5, and 9.0 min after the start of filling during a normal 1-min valve operation (Photo 1). Submergence of the roof of the intake ports was 48 ft. For this normal 84-ft lift condition (upper pool el 414), the approach was free of adverse vortex conditions.

16. During subsequent filling tests, the upstream lock approach was free of any tendency for vortexes to form under normal or single valve operations with upper pool el 422 (92-ft maximum lift), 414, or 408.

Alternate design

17. As a result of a value engineering proposal, consideration was given to raising the intake manifold invert from el 352 to 360. Model tests of this condition revealed the formation of persistent swirls over the intake ports. From past experience, persistent swirls in a 1:25-scale model indicate that vortexes will occur in the prototype.

Therefore, it was recommended that the type 1 (original) intake manifold with invert el 352 be retained in the type 17 (recommended) design filling system shown in Plate 9.

Crossover Culvert and Tuning Fork Sections

18. In the original design crossover culvert (Plate 3 and Figure 5), the 2-ft-thick horizontal splitter wall ensured that the rate of flow to both the upstream and downstream tuning forks was about equal for both normal and single valve operations. Good flow distribution at the crossover resulted in equal division of flow at the vertical divider in the tuning fork leading to the floor culverts. The area of the culvert increased from 196 sq ft in the wall to 252 sq ft in the longitudinal floor culverts downstream of the tuning forks (ratio of 1:1.29). The original design crossover and tuning forks were adopted as elements of the recommended design filling and emptying system.

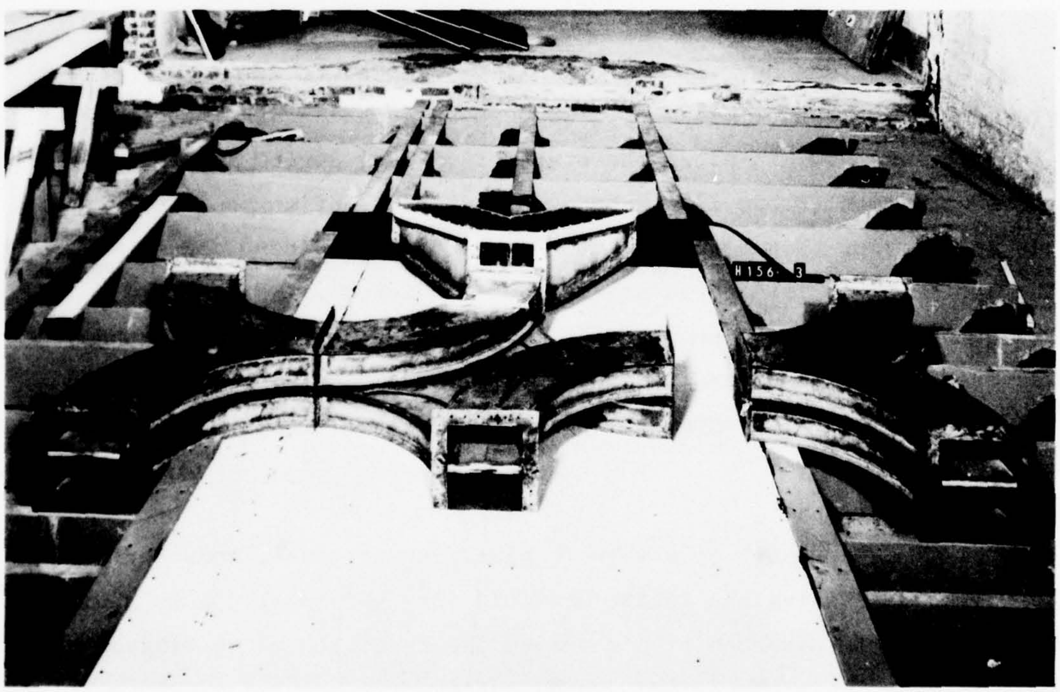

Figure 5. Original design crossover culvert

Floor Culvert Manifolds

Original design

19. The original design filling and emptying system included two longitudinal floor culverts extending both upstream and downstream from the tuning forks (Plate 3). The floor of the 14-ft-wide by 9-ft-high floor culverts was set at el 303, and the interior roof was set at el 312. The exterior roof was set at el 315, 15 ft below the lower pool el of 330. Each floor culvert consisted of 12 pairs of ports, each 1.5 ft wide by 3.5 ft high, spaced 15 ft on centers and positioned symmetrically about the quarter points of the chamber length (Plate 3). Each floor culvert had a port-to-culvert-area ratio of 1.00. However, an extra pair of ports was included in each end of the culverts during model construction to permit shifting the manifolds as well as to increase or reduce the manifold length and to vary the port-to-culvert-area ratios between 1.08, 1.00, and 0.92.

20. Baffling adjacent to the longitudinal floor culverts was included in the system as an integral part of the design since energy dissipation and control of subsurface and surface currents resulted in reduced hawser forces on moored tows and limited movement of free tows in the chamber. The original baffling is shown in Plate 3 and consisted of baffles located opposite the ports along the lock walls and along the center line of the lock. An overhanging ledge was provided above the ports which extended throughout the full length of each floor culvert.

21. With a 1-min valve time the lock filled in 9.9 min, and surface turbulence in the chamber was satisfactory (Photo 2). A free tow centered in the chamber moved longitudinally toward the miter gates, but when restrained (Plate 10) resulted in hawser forces of about 7 tons in both upstream and downstream directions. Transverse hawser forces were about 6.5 tons. Emptying hawser forces were less than 5 tons and the lock emptied in about 11.7 min with a 1-min valve time. Plate 11 is a plot of filling and emptying valve times versus valve time for normal and single valve operations.

Alternate designs

22. Tests were conducted with various manifold positions, as well as manifold port-to-culvert-area ratios and baffling arrangements as shown in Table 2. This table also indicates valve position and invert grade changes as well as outlet design changes. During these tests, observations were made of turbulence in the lock chamber and movement of free tows; and in some tests, hawser forces were measured. These tests revealed that the manifolds were optimum in their original location with the original number of ports (port-area-to-culvert-area ratio of 1:00) and port spacing. However, adjustments were needed to the vertical baffle supports to optimize energy dissipation.

23. In order to obtain both longitudinally and transversely balanced hawser forces on various sized tows moored at several positions in the lock chamber with normal and single valve operations, it was necessary to place the vertical support walls at different locations on each end of the lock. This was the only part of the system that was not symmetrical.

Recommended design

24. The floor culvert manifold recommended consisted of 12 pairs of ports, each 2.5 ft high by 1.5 ft wide. The ports were spaced 15 ft on centers, and the port groups were centered on the quarter points of the lock chamber. The vertical wall at the end of the areas between the floor culverts was changed to slope up 12 ft in a distance of 15 ft. The horizontal overhanging baffles adjacent to the floor manifold were not changed except to extend them into the sloping wall at the end of the culverts. However, along the center-line T-wall and each berm wall overhang, vertical baffles or wall supports were provided on each side of ports 1-8 in the upstream end of the chamber and on each side of ports 2-9 in the downstream end of the chamber. The vertical baffles or supports were extended out the same distance (2.0 ft) as the overhangs on the berm walls and the T-wall, and these were very critical to lock performance. Details of the recommended manifolds and baffling are shown in Plate 9.

Outlet Manifold and Downstream Approach

Original design

25. The type 1 (original) outlets shown in Plate 3 were installed within the 300-ft canal width as shown in Figure 3. Single outlet manifolds were positioned between the lower lock walls downstream of and normal to both the left and right wall culverts and transition sections. The ports were staggered at sta 6+80 and 7+00 in the opposing lateral manifolds for better dissipation of energy in the basins (invert el 298). Two additional lateral manifolds were provided on the left culvert at sta 7+20D and 7+60D between the guide wall and left bank of the canal. Two lateral manifolds were provided on the right culvert at sta 7+40D and 7+80D between the guide wall and right bank of the canal. These outlets did not distribute flow equally across the canal. However, a decision by ORN involving realignment of the lock chamber and downstream canal precluded revision of the culvert outlets as originally designed.

Alternate design

26. ORN prepared details of the type 2 outlet laterals, guard wall, guide wall, and canal alignment shown in Plate 12 and Figure 6. The discharge laterals were changed from the original arrangement to an arrangement in which the left culvert discharge lateral was located to the left of the guard wall and the right culvert discharge lateral was positioned between the lock approach walls. A shift of the downstream channel alignment 76 ft to the east was made to improve the navigational approach downstream of the lock. These changes were made based on the results of previous model studies and discussions between ORN, U. S. Army Engineer District, Mobile, and U. S. Army Engineer Waterways Experiment Station (WES) engineers. The floor elevation of the lateral diffuser was the same as the wall culvert floor elevation (298). Each lateral had eight pairs of equal-sized ports 3 ft wide by 6 ft high. Energy dissipation was accomplished by the impact of the jets of water against a vertical wall positioned 10 ft from the face of the ports. Velocities and distribution of flow in the left culvert outlet measured under steady-flow conditions are shown in Plate 13 and were considered

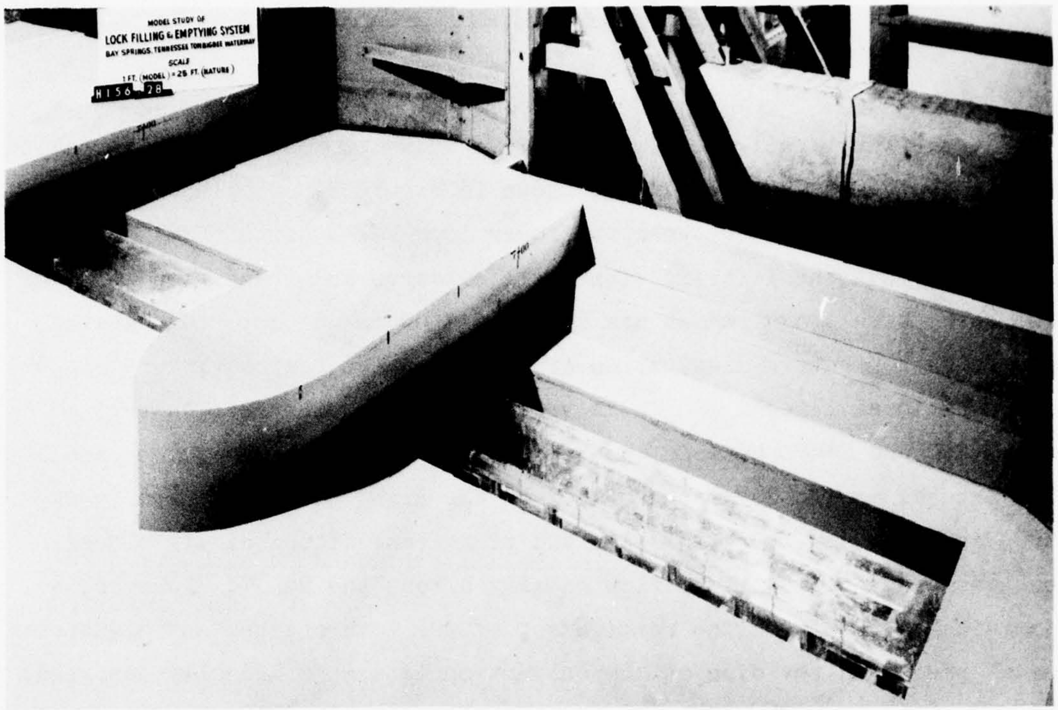

Figure 6. Type 2 outlet and guard wall immediately downstream of lock chamber

satisfactory. Photo 3 shows maximum flow conditions during 1- and 2-min normal and 2-min single valve emptying operations. With normal operations, flow was well distributed across the downstream canal. Single valve operations distributed the flow initially into one half of the approach, but then the flow spread rapidly over the full width of the canal. The type 2 outlet manifold was adopted for use in the recommended filling and emptying system.

Pressures on Culvert Roof Downstream of Filling and Emptying Valves

Original design

27. Flow entering or leaving the lock chamber was controlled by two reverse tainter valves. The wall culverts were 14 ft high by 14 ft wide and their inverts sloped from el 352 just downstream of the intake manifold to el 311 at sta 0+72, just upstream of the filling valves.

This provided a submergence of 5 ft below lower pool (el 330) with the roof of the filling valve at el 325. The emptying valves were identical with the filling valves. However, the inverts of the emptying valves were located at el 298; the roofs, at el 312. This provided 18 ft of submergence below the lower pool. The original design valve positions are shown in Plate 3.

28. Pressure data were recorded during operations with 78-, 84-, and 92-ft lifts and normal tailwater (el 330). Subatmospheric pressures were observed on the roof of the culverts immediately downstream of the filling valve at sta 1+32.50D and the emptying valve at sta 5+19.02D (Plate 8). These pressures are plotted versus filling and emptying times for valve times of 1, 2, and 4 min in Plate 14. The bulkhead slots downstream of the valves were sealed to prevent uncontrolled quantities of air from entering the model culverts. Available data indicate that these subatmospheric pressures in conjunction with the velocities under the valves would produce cavitation in the cores of vortexes shed from the valve lip. This condition can be relieved by lowering the filling valves 5 to 7 ft to allow for the controlled admission of air. The pressure condition at the emptying valve can also be relieved by the controlled admission of air. Thus, it is recommended that two 12-in.-diam air vents be installed on the roof of the prototype culverts. Further, it is suggested that control valves be installed near the top of the lock wall so that regulation of the optimum amount of air needed for adequate venting can be accomplished in the field. Air entering the culverts during the valve opening period will be controlled and well entrained in the high-velocity flow and will be purged from the system shortly after the valves reach the fully open position. Small bubbles can be expected to rise to the surface throughout the lock chamber for a short period during the filling operation.

<u>Alternate designs</u>

29. ORN prepared details for lowering the filling valves 7 ft to invert el 304 and repositioning the valves 70 ft upstream of the original position to provide for a filling valve roof submergence of 12 ft below the lower pool and a greater length between the valve and the

crossover culvert. This revision was designated type 2 filling valves and is shown in Plate 9. In conjunction with the valve relocation, wall culvert modifications upstream to the intake and downstream to the crossover culvert were required. The culvert floor below the filling valves sloped from el 304 to el 296 which provided the crossover culverts with 18 ft of submergence below the lower pool (el 330). Plates 15 and 16 are plots of high, observed average, and low pressures measured below the filling valves with 1-, 2-, and 4-min normal and single (left only) valve filling operations. Piezometer locations are shown in Plate 17. The pressure cell was located at sta 0+62.55D on the left wall culvert (Plate 17). This modification decreased minimum pressures downstream from the filling valves to a satisfactory level provided a controlled amount of air is admitted to the system.

30. During emptying, the back pressure created at the emptying valves by the type 2 outlet raised the average minimum pressures below the valves (Plate 15) above those observed with the original outlet (Plate 14). Average pressure readings with steady-flow conditions are listed in Table 3. Lock emptying times were increased by 0.5 to 1 min. With the adopted type 2 outlet, a 2-min valve schedule is preferable to the 1-min valve with the culvert roof at el 312. The negative pressures with a 2-min valve time for normal and single valve operation (Plates 15 and 16) assure adequate admission of controlled air to relieve possible cavitation conditions. The pressures with a 1-min valve time, as indicated by the model pressure cell, do not appear to be adequate to relieve the cavitation conditions.

Recommended Filling and Emptying System (Type 17)

31. Pertinent features of the filling and emptying system recommended for Bay Springs Lock are shown in Plate 9. The type 17 design included the original upstream guide and guard walls, intakes, crossover culvert, tuning fork, and emptying valve locations; the type 2 filling valves; type 2 outlet manifold; and the floor culvert manifold shown in Plate 9.

32. Flow conditions in the lock chamber during a filling operation were excellent with only a very small degree of surface turbulence. Photo 4 shows conditions in the lock chamber during filling. Plates 18-21 show hawser forces versus filling and emptying times for 1-, 2-, and 4-min valve times for lifts of 78, 84, and 92 ft. A plot of valve times versus filling and emptying times for normal and single valve operations is shown in Plate 22. Unmoored tows in the lock either rose vertically or drifted slowly away from the nearest gate. This is an important safety feature, and should not be misinterpreted to indicate that tows should not be moored in the lock chamber. Plate 23 shows free tow movement during normal filling operations.

33. Characteristics to be expected with the type 17 system during filling and emptying are dependent on the valve times selected. A 1-min valve time is recommended for filling with normal or single valve operation and the normal lift of 84 ft. Filling times in the model were 10.5 min and 20.5 min, respectively. For emptying, a 2-min valve time is recommended and model emptying times were 13.3 min for normal and 24.6 min for single valve operations. It has been established from experience that a prototype lock will fill faster than will the 1:25-scale model, but conditions in the prototype will be satisfactory if the valves are operated at a rate no faster than will be required to limit hawser forces to a 5-ton limit in the model. Recent prototype tests of the Bankhead Lock, Black Warrior River, Alabama, with a system similar to Bay Springs Lock but with a 69-ft lift revealed an 18 percent reduction in filling times relative to those measured in 1:25-scale model tests with a 1-min valve time. The schedule of valve opening percent versus valve time percent for all valve speeds investigated for Bay Springs is plotted in Plate 5. The prototype filling times should be about 18 percent less than the times shown in Plate 22.

34. Plate 17 shows piezometer locations throughout the lock system. In order to record average pressures throughout the filling and emptying system, the piezometer boards were primed and dyed and sequentially photographed during normal and single culvert filling and emptying operations with normal lift conditions and the recommended

1-min filling and 2-min emptying valves. These average pressure data are listed in Tables 4-7.

35. Overall lock coefficients, based on the normal filling and emptying data presented in Plate 22, were computed by the equation:

$$C_L = \frac{2A_L(\sqrt{H + d} - \sqrt{d})}{A_c(T - Kt_v)\sqrt{2g}}$$

where

A_L = area of lock chamber, sq ft
H = initial head, ft
d = measured overfill, ft
A_c = area of culvert, sq ft
T = filling or emptying time, sec
K = a constant
t_v = valve time, sec
g = acceleration due to gravity, ft/sec^2

The term $T - Kt_v$ is the lock filling or emptying time for the hypothetical case of instantaneous valve opening and can be obtained by extrapolation of the data presented in Plate 22. Computed coefficients for the type 17 system are 0.64 for filling and 0.56 for emptying.

Large Barge Tests

36. Subsequent to completion of the model investigation, a request to measure hawser forces on a wider and longer tow was received from the U. S. Army Engineer Division, South Atlantic (SAD), and tests were made with 390- and 585-ft-long tows that had widths of 105 ft and drafts of 9 ft. These data are plotted in Plate 24.

Head Differential Across Miter Gates and Programmed Valves

37. The head differential that occurs across the downstream miter

gate as a result of overemptying a lock chamber (the water surface immediately downstream of the lower miter gates is above that in the chamber after the lock empties) tends to open the miter gates. The magnitude of this head differential was desired in order to design the miter gates and operating machinery. Wave rods were installed at sta 7+30.75D over the left culvert outlet to record water-surface elevations during emptying operations with the normal 84-ft lift and valve times of 1, 2, and 4 min. In addition, coincidental water-surface elevations in the chamber were recorded. Data for single (left) culvert operations with 1- and 2-min valves were also obtained (Table 8). The maximum differential measured across the miter gate with a normal 2-min emptying valve operation was 1.05 ft. A value of about 1.3 ft may occur in the prototype assuming it will empty in about 10.9 min (82 percent of that indicated by the model) without proper programming of the emptying valves.

38. Similarly, about 1.3 ft of overfilling might be experienced in the prototype due to the faster filling time anticipated (8.6 min) with normal operations and without proper programming of the filling valves. It is recommended that closure of the filling valves (1-min schedule) be initiated approximately 7.8 min after start of the filling operation and that closure of the emptying valves (2-min schedule) be initiated approximately 9.4 min after start of the emptying operations. These times should be refined in the prototype structure after operation begins. This should prevent any significant overfilling or overemptying of the lock chamber relative to the water-surface elevations of the upper and lower approaches.

Reservoir Evacuation Through Filling and Emptying System

39. The lock culverts will be used to lower Bay Springs Reservoir in the event of an emergency. Three plans of operation to accomplish this evacuation were furnished by ORN and are shown in Plate 25. These three methods were simulated in the model. Pertinent water-surface elevations, flow conditions at the intakes, and average negative pressure readings observed at piezometers in the system during these

tests are listed in Tables 9-11. Terminology to describe vortex formations at the intakes was defined in paragraph 14. Two openings are provided in the upstream guide wall in two monoliths located just upstream from the culvert intake. These openings are 20 ft wide by 47 ft high with inverts at el 352 to provide a means of lowering the pool water level from the top of the water-quality control dike (el 384) to el 352 in case drawdown of the reservoir is required for maintenance work on the dam or for other reasons.

Generalized Tests

40. Generalized tests* were made with the type 17 (recommended) filling and emptying system for lifts of 58, 68, 78, 84, and 92 ft and submergences of 14, 17, and 20 ft over the lock floor. A four-barge tow at position 4 in the downstream end of the chamber (Plate 4) was used to measure hawser forces during filling and emptying with 1-, 2-, and 4-min valve times. Plate 26 is a plot of filling times for 3-, 4-, and 5-ton hawser force limits indicating the effect of submergence and head variations. The filling and emptying times for normal valve operation for the 58- and 68-ft lifts are plotted in Plate 22. Hawser forces during all generalized emptying tests were about 3 tons.

41. Minimum pressure cell readings were recorded immediately downstream of the left culvert filling and emptying valves at sta 0+62.55D and 5+19.02D (Plate 14) during the generalized tests. High, observed average, and low pressures during filling and emptying operations with normal 1-, 2-, and 4-min valve times are plotted in Plates 27 and 28.

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* Funded by CWIS Work Unit No. 31076 "Improved Criteria for Lock Design."

PART IV: DISCUSSION AND RECOMMENDATIONS

42. Because of the high lift involved (84 ft normal), model studies were needed to determine the adequacy of the various elements of the filling and emptying system and to ensure that the proposed system will provide a safe and efficient means for filling and emptying the lock. Results of the model tests verified the effectiveness of the proposed design filling and emptying system and were used to develop modifications to the filling valves, floor culvert manifolds and baffling, and outlets in the downstream canal approach.

43. Flow conditions in the upstream approach and at the 10-port type 1 (original) design intake were found to be satisfactory and vortex-free. Tests with the intake invert raised 8 ft resulted in the formation of persistent swirls over the intake ports; and from past experience, persistent swirls in 1:25-scale models indicate that vortexes would occur in the prototype. Therefore, the type 1 intake with invert el 352 was adopted for the recommended system.

44. The filling valves were repositioned 70 ft upstream and lowered 7 ft to invert el 304 to obtain desired negative pressure conditions on the roof of the culvert immediately downstream of the valves during the period of valve opening (40 to 60 percent) when cavitation could occur. The cavitation will be relieved by the controlled admission of air through two 12-in.-diam air vents installed about 7 ft downstream of the valve in the culvert roof with controls installed at a higher elevation in the valve machinery area. The bulkhead slots downstream of the valves should be sealed to prevent uncontrolled quantities of air from entering the culverts and system. The adjustment of the air vent controls should be accomplished at the prototype structure by OCE, SAD, ORN, and WES engineers. The emptying valves as originally positioned at invert el 298 are recommended. Sealing of the bulkhead slots and addition of the 12-in.-diam air vents with controls as described above will be required. This condition exists at filling valves in Holt and Bankhead Locks on the Warrior River and is relieved in a satisfactory manner by air vents and the controlled admission of air.

45. With the type 17 system and a 1-min valve, the lock chamber filled in 10.5 min; and with a 2-min valve, the lock chamber emptied in 13.3 min. Due to differences in friction losses, the prototype can be expected to fill and empty about 18 percent faster than the model (8.6 and 10.9 min, respectively). Flow conditions in the lock chamber were excellent with a very small degree of turbulence. Unmoored half tows in the chamber rose vertically or drifted toward the center of the lock chamber, and full tows drifted very slowly about 20 ft toward the lower miter gate during the latter part of the filling operations. Unmoored tows should not be permitted in locks, but this performance indicates built-in safety for this longitudinal floor culvert system. The system as developed is not sensitive to misoperation as were most systems used in the past; thus a large factor of safety against dangerous conditions resulting from misoperation is not required. However, the filling and emptying valves should be programmed as recommended in paragraph 38.

46. In the type 17 system, a horizontal divider wall beginning at the junction of the wall culvert with the crossover culvert allows flow in the top and bottom halves of the culvert to be directed, respectively, into the two ends of the lock chamber through the tuning fork and floor culverts. Relatively long radius bends are possible and flow instabilities are avoided. Thus single valve operation does not result in flow instabilities and undesirable distribution of flow into the two ends of the lock chamber.

47. The unsymmetrical baffling around the floor culvert manifolds is the key to energy dissipation and control which results in the fast filling time and low hawser forces and only minor movement of a free tow with this high lift system. The baffling actually optimizes and directs flow released through the culvert crossover, tuning fork, and finally the manifold ports. Adjustment of the manifold baffling for the recommended design was one of the most important results of the model investigation.

48. The relocation and modification of the outlet manifold resulted in good distribution of flow released in the lower lock approach and canal downstream of the lock with a 2-min emptying valve schedule

that was needed to prevent adverse flow conditions in the lower approach. However, this design raised pressures downstream from the emptying valves and indicated further justification for the 2-min emptying valve time to assure adequate admission of air needed to prevent possible cavitation conditions.

49. When this bottom longitudinal filling and emptying system is used in a 1200-ft-long lock, flow must be further subdivided in each end of the lock chamber. A total of eight rather than four floor culverts will be required.

50. The type 17 filling and emptying system was used to investigate three plans of reservoir evacuation, should such an emergency or need occur. In addition, the water-surface differential that occurred across the miter gate during undertravel when emptying the lock was determined to assist in design of the miter gates and operating machinery. Programmed valve operations (paragraph 38) are recommended to prevent significant overfilling and overemptying.

51. The dimensions of the hydraulic passages and the ratios of the areas of the passages to the area of the wall culverts at the valves are shown in the following tabulation:

Water Passage per Culvert	Area sq ft	Area Ratio Passage/Culvert at Valve
Wall culvert at valves	196.0	1.0
Intake at entrance	980.0	5.0
Intake at throats	345.1	1.76
Culvert at crossover	196.0	1.0
Culvert at manifold	252.0	1.29
Culvert ports	252.0	1.29
Outlet at entrance	217.0	1.11
Outlet at ports	288.0	1.47

Table 1

Average Pressures in Filling System

Steady-Flow Conditions, Type 1 (Original) Design

No.	Station	Piezometer Elevation	Piezometer Reading	Pressure
		Intake Culvert (Left)		
1	2+42.25U	352.0	407.3	55.3
2	2+41.5U		405.0	53.0
3	2+28.25U		402.5	50.5
4	2+17.12U		399.3	47.3
5	2+05U		397.0	45.0
6	1+93U		395.0	43.0
7	1+80.5U		392.7	40.7
8	1+68.75U		390.7	38.7
9	1+56.50U		388.6	36.6
10	1+44.50U		386.5	34.5
11	2+29.5U		403.6	51.6
12	2+17.5U		400.6	48.6
13	2+05U		398.0	46.0
14	1+93.25U		395.8	43.8
15	1+80.75U		393.6	41.6
16	1+68.5U		391.5	39.5
17	1+56.25		389.7	37.7
18	1+44.00U		387.0	35.0
19	1+18.00U		370.5	18.5
		Filling Valve (Left)		
1	0+75.4D	311.0	364.3	53.3
2R	0+96D	311.0	362.1	51.1
3L		318.0	362.0	44.0
4T		325.0	362.0	37.0
5R		318.0	361.8	43.8
6	1+27.50D	318.0	362.6	44.6
7	1+37.50D	311.0	358.3	47.3
8L		318.0	359.0	41.0
9		325.0	359.8	34.8
10R		318.0	359.2	41.2
11B	1+45.50D	310.9	351.2	40.3
12T	1+50.50D	324.9	364.2	39.3
13B	1+45.50D	310.4	352.0	41.6
14T	1+50.50D	324.4	364.2	39.8
15B	1+76	304.5	358.4	53.9
16L		311.5	358.1	46.6
17T		318.5	358.4	39.9
18R		311.5	357.9	46.4

No.	Station	Piezometer Elevation	Piezometer Reading	Pressure
		Transition to Crossover Culvert (Left)		
1	2+03.48D	312.7	363.1	64.4
2	2+03.48D	298.7	351.0	52.3
3	2+40.52D	296.0	360.9	64.9
4	2+40.52D	312.0	359.9	47.9
		Crossover Culvert (Left and Right)		
1S	2+43.48D	304.0	410.0	106.0
2TS	2+55.35D	308.5	332.3	23.8
2BS	2+55.35D	299.5	328.5	29.0
3BS	2+55.35D	308.5	324.2	15.7
4TS	3+07.65D	299.5	333.0	33.5
5S	3+19.52D	304.0	335.9	31.9
7TS	2+55.35D	308.5	327.0	18.5
8BS	3+07.65D	299.5	324.5	25.0
		Tuning Fork (Downstream) and Left Floor Culvert		
1	3+24.52D	296.0	348.2	52.2
2	3+32.5D	296.75	357.2	60.45
3	3+37.52D	305.0	375.6	70.6
4D	3+62.00D	303.0	343.7	40.7
5D	4+49.50D		358.6	55.6
6D	5+24.50D		364.6	61.6
4U	2+01.00D		345.7	42.7
5U	1+13.50D		357.6	54.6
6U	0+38.50D		363.7	60.7

Note: Steady-flow test conditions, upper miter gates closed, filling valves open; lower miter gates open, emptying valves closed. Upper pool el 414, lower pool el 341. Pressures are in prototype feet of water.

Table 2

Lock Filling and Emptying Systems, Types 1-17

Filling and Emptying Systems Type	Intake Manifold Type	Filling Valves Type	Filling Valves Invert	Floor Culverts: Upstream Manifolds	Floor Culverts: Downstream Manifolds	Manifold Baffling Type	Manifold Baffling	Emptying Valves Type	Emptying Valves Invert	Outlet Type
1	1	1	311	12 $P_A/C_A = 1.00$ 1 0+31D 1+96D	1 12 3+67D 5+32D	1		1	298	1
2	1	1	311	13 $P_A/C_A = 1.08$ 1 0+16D 1+96D	1 13 3+67D 5+47D	1		1	298	1
3	1	1	311	13 $P_A/C_A = 1.00$ 2 0+16D 1+81D	2 13 3+82D 5+47D	1		1	298	1
4	1	1	311	12 $P_A/C_A = 0.92$ 2 0+31D 1+81D	2 12 3+82D 5+32D	1		1	298	1
5	1	1	311	13 $P_A/C_A = 0.92$ 3 0+16D 1+66D	3 13 3+97D 5+47D	1		1	298	1
6	1	1	311	11 $P_A/C_A = 0.92$ 1 0+46D 1+96D	1 11 3+67D 5+17D	1		1	298	1
7	1	2	304	12 $P_A/C_A = 1.00$ 1 0+31D 1+96D	1 12 3+67D 5+32D	1	With vertical dividers at T-wall and outside wall baffles every other port	1	298	1
8	1	2	304	13 $P_A/C_A = 1.08$ 1 0+16D 1+96D	1 13 3+67D 5+47D	1	As above type 7 arrangement	1	298	1
9	1	2	304	12 $P_A/C_A = 1.00$ 1 0+31D 1+96D	1 12 3+67D 5+32D	1	With vertical dividers at T-wall and outside wall baffles between every port	1	298	1
10	1	2	304	13 $P_A/C_A = 1.08$ 1 0+16D 1+96D	1 13 3+67D 5+47D	1	As above type 9 arrangement	1	298	1
11	1	2	304	13 $P_A/C_A = 1.08$ 1 0+16D 1+96D	1 13 3+67D 5+47D	1	With vertical dividers at T-wall and outside wall baffles between every port. With overhang above manifolds removed	1	298	1
12	1	2	304	12 $P_A/C_A = 1.00$ 1 0+31D 1+96D	1 12 3+67D 5+32D	1	As above type 11 arrangement	1	298	1
13*	1	2	304	13 $P_A/C_A = 1.08$ 1 0+16D 1+96D	1 $P_A/C_A = 0.92$ 11 3+67D 5+17D	1	As above type 11 arrangement	1	298	1
14*	1	2	304	13 $P_A/C_A = 1.08$ 1 0+16D 1+96D	1 $P_A/C_A = 1.00$ 12 3+67D 5+32D	1	As above type 9 arrangement	1	298	1
15*	1	2	304	13 $P_A/C_A = 1.08$ 1 0+16D 1+96D	1 $P_A/C_A = 0.92$ 11 3+67D 5+17D	1	As above type 9 arrangement	1	298	1
16	1	2	304	12 $P_A/C_A = 1.00$ 1 0+31D 1+96D	1 12 3+67D 5+32D	1	As above type 9 arrangement	1	298	2
17	1	2	304	12 $P_A/C_A = 1.00$ 1 0+31D 1+96D	1 12 3+67D 5+32D		See Plate 9	1	298	2

Note: The lock chamber is 110 ft wide by 670 ft long, pintle to pintle. Stations are measured from upstream miter gate pintle 0+50U. Wall culverts are 14 ft wide by 14 ft high. Floor culverts are 14 ft wide by 9 ft high. Ports are 1.5 ft wide by 3.5 ft high. Center line of crossover culvert sta 2+81.50D type 1 intakes, filling valve, manifold baffles, emptying valves, and outlets were original design.

* Port-to-culvert-area ratios for upstream and downstream floor culvert manifold were not equal.

Table 3

Average Pressures in Emptying System

Steady-Flow Conditions, Type 9 Floor Culverts, Type 2 Outlet

No.	Piezometer Station	Piezometer Elevation	Piezometer Reading	Pressure
	Floor Culvert (Left)			
4U	2+01.00D	303.0	358.4	55.4
5U	1+13.50D		364.3	61.3
6U	0+38.50D		365.3	62.3
4D	3+62.00D		355.6	52.6
5D	4+49.50D		364.6	61.6
6D	5+24.50D		366.0	63.0
	Floor Culvert (Right)			
4U	2+01.00D	303.0	358.1	55.1
5U	1+13.50D		364.2	61.2
4D	3+62.00D		352.8	49.8
5D	4+49.50D		364.4	61.4
	Tuning Fork (Upstream)			
1	2+38.48D	296.0	354.5	58.5
2	2+30.48D	296.75	357.8	61.0
3N	2+25.48D	305.0	357.3	52.3
	Tuning Fork (Downstream)			
1	3+24.52D	296.0	358.5	62.5
2	3+32.52D	296.75	361.5	64.7
3N	3+37.52D	305.0	360.5	55.5
	Crossover Culvert			
1S	2+43.48D	304.0	352.2	48.2
2TS	2+55.35D	308.5	351.7	43.2
2BS	2+55.35D	299.5	352.3	52.8
3BS	2+55.35D	299.5	344.5	45.0
4TS	3+07.65D	308.5	337.8	29.3
5S	3+19.52D	304.0	361.0	57.0
6S	2+43.48D	304.0	362.2	58.2
7TS	2+55.35D	308.5	347.5	39.0
8BS	3+07.65D	299.5	336.7	37.2
9S	3+19.52D	304.8	341.0	37.0
	Transition and Left Culvert			
1	3+22.02D	312.0	343.5	31.5
2	3+22.02D	296.0	343.2	47.2
3B	4+04.52D	298.0	340.5	42.5
4L	4+04.52D	305.0	340.5	35.5
5T	4+04.52D	312.0	340.5	28.5
6R	4+04.52D	305.0	340.5	35.5

No.	Piezometer Station	Piezometer Elevation	Piezometer Reading	Pressure
	Emptying Valve (Left)			
1B	4+82.52D	298.0	339.2	41.2
2L	4+82.52D	305.0	339.1	34.1
3T	4+82.52D	312.0	340.1	28.1
4R	4+82.52D	305.0	339.2	34.2
5	5+14.02D	312.0	338.0	26.0
6B	5+24.02D	298.0	338.0	40.0
7L	5+24.02D	305.0	337.8	32.8
8T	5+24.02D	312.0	338.1	26.1
9R	5+24.02D	305.0	338.0	33.0
10	5+34.02D	312.0	338.8	26.8
11	5+39.02D		338.0	26.0
12	5+44.02D		338.0	26.0
13	5+49.02D		337.7	25.7
14	5+54.02D		338.1	26.1
	Culvert (Left) and Outlet			
1B	6+12.00D	298.0	336.7	38.7
2L	6+12.00D	305.0	336.0	31.0
3T	6+12.00D	312.0	353.7	41.7
4R	6+12.00D	305.0	335.6	30.6
5B	6+47.00D	298.0	335.1	37.1
6L	6+47.00D	305.0	335.1	30.1
7T	6+47.00D	312.0		
8R	6+47.00D	305.0	335.2	30.2
9	7+30.75D	298.0	335.2	37.2
10	7+30.75D	298.0	336.2	38.2
11	7+30.75D	298.0	339.3	41.3
	Culvert (Right)			
12B	6+47.00D	298.0	334.7	36.7
13L	6+47.00D	305.0	335.0	30.0
14T	6+47.00D	312.0		
15R	6+47.00D	305.0	335.3	30.3

Note: Steady-flow test conditions upper miter gates open, filling valves closed; lower miter gates open, emptying valves open full. Upper pool el 407.2, lower pool el 303.0. Pressures are in prototype feet of water.

Table 4

Average Piezometer Readings During Filling, Type 17 Filling Arrangement, 84-Ft Lift

Upper Pool El 414, Lower Pool El 330, Normal 1-Min Valve Operation

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water															
No.	Station	Elevation	T=15* LC=330.3**	T=30 LC=331.4	T=45 LC=334.0	T=60 LC=337.5	T=75 LC=342.2	T=90 LC=346.2	T=120 LC=354.9	T=150 LC=362.2	T=180 LC=369.0	T=210 LC=380.6	T=300 LC=389.9	T=360 LC=397.5	T=420 LC=403.3	T=480 LC=408.0	T=540 LC=411.3	T=600 LC=413.6
Intake (Left Wall)																		
1	2+42.25U	352.0	414.0	413.0	411.8	409.2	408.0	407.8	408.3	408.9	409.5	410.7	411.4	412.3	412.9	413.3	413.8	414.0
2	2+41.5U			413.2	411.3	408.3	406.4	406.3	407.1	407.8	408.5	409.9	410.9	411.9	412.7	413.2	413.7	414.0
3	2+28.25U			412.9	410.3	406.6	403.7	403.7	404.6	405.8	406.7	408.4	410.0	411.0	412.1	412.8	413.3	413.8
4	2+17.12U			412.4	409.9	404.5	400.7	400.7	402.0	403.3	404.8	406.2	408.2	409.9	411.3	412.5	413.3	413.9
5	2+05U			412.4	409.0	403.7	399.7	399.1	400.3	401.8	403.3	405.8	407.9	409.7	411.2	412.3	413.2	413.6
6	1+93U			412.1	408.2	402.3	397.9	397.7	399.2	400.7	402.1	404.8	407.3	409.3	410.9	412.2	413.2	413.8
7	1+80.5U		413.8	411.3	406.8	400.1	395.4	395.8	397.0	398.8	401.7	404.2	406.3	408.9	410.8	412.0	413.0	413.8
8	1+68.75U		413.8	411.3	406.2	399.0	394.1	394.4	396.4	398.5	400.2	403.4	406.3	408.7	410.6	412.0	413.1	413.8
9	1+56.50U		413.7	410.9	405.7	397.7	392.1	392.2	394.3	396.3	398.7	402.2	405.3	407.9	410.1	411.8	412.9	413.7
10	1+44.50U		413.6	410.2	403.7	394.3	387.9	388.0	390.7	393.3	395.7	400.0	403.7	406.8	409.3	411.3	412.7	413.7
11	2+29.5U		414.3	412.9	410.6	406.8	404.4	404.6	405.3	401.3	407.3	408.8	410.2	411.3	412.3	413.0	413.7	414.0
12	2+17.5U		414.2	412.6	409.5	404.8	401.6	401.7	402.8	404.0	405.2	407.2	409.4	410.6	411.7	412.8	413.5	414.0
13	2+05U		414.0	412.2	408.7	403.3	399.2	399.3	400.7	402.1	403.6	406.0	408.0	409.9	411.3	412.2	413.3	413.8
14	1+93.25U		414.0	411.9	407.6	401.1	396.9	397.2	398.9	400.4	402.0	404.9	407.3	409.2	410.9	412.2	413.2	413.8
15	1+80.75U		414.0	411.8	407.1	400.1	395.0	395.0	396.8	398.7	400.3	403.7	406.2	408.6	410.4	411.9	413.0	413.6
16	1+68.5U		413.8	411.2	405.8	397.9	392.9	393.3	395.3	397.3	399.1	402.8	405.7	408.1	410.2	411.8	413.0	413.7
17	1+56.25U		413.8	411.2	405.7	397.7	391.7	391.4	393.7	395.8	397.9	406.7	404.9	407.6	409.8	411.6	412.9	413.7
18	1+44.00U		413.5	410.3	403.7	394.3	388.3	388.8	391.3	393.8	396.0	405.2	403.8	406.9	409.3	411.3	412.8	413.7
19	1+18U		412.8	408.2	397.0	382.5	373.7	374.8	378.8	385.0	385.0	392.8	398.2	402.9	406.8	409.8	412.0	413.4
Filling Valve (Left Wall)																		
1B	0+16.00D	304.0	410.3	405.0	392.3	375.7	366.9	368.6	373.1	377.3	383.0	389.1	395.7	401.1	405.6	409.0	411.8	413.4
2L	0+16.00D	311.0	410.3	404.9	391.6	376.3	366.0	366.7	371.4	375.8	380.2	387.8	394.9	400.7	405.3	408.9	411.8	413.4
3T	0+16.00D	318.0	410.9	405.2	392.8	375.4	364.3	365.3	370.3	374.9	379.3	387.4	394.3	400.1	404.9	408.8	411.6	413.4
4R	0+16.00D	311.0	410.8	405.2	392.4	376.3	365.8	366.4	371.2	375.7	380.1	388.0	394.7	400.5	405.1	408.9	411.7	413.3
5	0+26.00D	318.0	409.9	404.3	390.3	372.3	363.9	366.3	371.1	375.7	380.1	388.0	394.7	400.6	405.1	408.9	411.6	413.3
6	0+57.55D		328.9	316.5	313.8	336.9	358.9	360.8	365.5	370.7	374.6	382.5	390.6	396.3	401.1	405.0	407.9	409.8
7	0+67.55D		328.8	317.6	313.6	335.0	358.8	363.8	368.9	373.7	378.0	386.7	393.8	399.7	404.7	408.4	411.2	413.1
8	0+78.00D		329.3	320.9	316.8	335.4	354.0	361.3	362.6	372.4	377.0	385.6	392.8	398.9	404.0	407.9	410.9	413.0
9	0+83.00D		329.7	321.3	319.9	340.7	357.2	363.0	363.7	373.5	378.0	386.3	393.7	399.6	404.4	408.3	411.2	
10B	0+88.00D	304.0	330.8	323.9	322.7	340.7	354.8	360.6	361.4	371.3	376.1	385.0	397.2	398.7	403.9	407.9	409.0	
11L	0+88.00D	311.0	330.7	323.0	323.0	341.5	356.3	361.9	362.7	372.6	377.1	385.7	392.8	398.9	404.0	408.1	410.9	
12T	0+88.00D	318.0	330.6	321.2	322.6	347.3	360.8	364.0	364.0	373.9	378.3	386.6	393.4	399.4	404.3	408.2	410.9	412.8
13R	0+58.00D	311.0	330.2	321.8	323.4	345.3	359.2	363.2	363.3	373.1	377.8	386.2	393.3	399.3	404.3	408.3	411.2	413.1
14	0+98.00D	303.7	332.2	326.7	322.2	333.3	344.6	351.1	359.0	364.9	370.3	380.3	388.7	396.1	402.0	406.7	410.2	412.7
15	1+21.41D	315.0	333.3	334.0	335.6	347.7	356.8	361.3	367.0	371.9	376.6	386.2	393.8	398.9	404.0	408.0	411.0	413.0
16	1+34.81D	312.0	333.3	337.3	340.9	348.7	354.7	358.4	364.2	369.4	374.3	384.0	391.3	397.9	403.4	407.7	410.7	412.8
17T	1+55.00D	298.0	334.0	338.8	343.3	351.8	356.3	360.6	366.0	371.0	375.8	385.0	393.1	398.7	403.9	408.0	411.1	413.2
18B	1+55.00D	312.0	334.3	339.0	343.9	352.2	356.4	360.4	366.0	371.0	375.8	385.0	393.3	398.7	403.8	408.0	411.1	413.1

(Continued)

Note: Elevations are in feet referred to mean sea level. 1-min valve schedule fills lock in 10.5 min. Bulkhead slots and air vents below filling valves closed.
* T is time (in prototype seconds) after beginning of filling operation.
** LC is elevation of water surface in lock chamber.

Table 4 (Concluded)

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water															
No.	Station	Elevation	T=15 LC=330.3	T=30 LC=331.4	T=45 LC=334.0	T=60 LC=337.5	T=75 LC=342.2	T=90 LC=346.2	T=120 LC=354.9	T=150 LC=362.2	T=180 LC=369.0	T=210 LC=380.6	T=300 LC=389.9	T=360 LC=397.5	T=420 LC=403.3	T=480 LC=408.0	T=540 LC=411.3	T=600 LC=413.6
Transition to Crossover Culvert (Left)																		
1	2+13.48D	312.0	332.8	336.9	342.2	349.0	354.5	358.3	364.0	369.4	374.4	383.0	391.4	398.0	403.6	407.6	411.0	413.0
2	2+40.98D	312.0	332.4	336.7	343.0	351.6	358.3	362.3	367.8	372.8	377.4	385.7	393.1	399.1	404.2	408.1	411.3	413.2
3	2+40.98D	296.0	332.8	337.1	343.2	352.2	359.3	363.0	368.3	373.2	377.7	386.1	393.3	399.3	404.2	408.2	411.3	413.2
Crossover Culvert																		
1S	2+43.48D	304.0	332.8	340.0	356.0	379.3	395.3	400.9	403.0	404.7	405.6	407.8	409.0	410.7	412.1	413.0	413.7	414.3
2TS	2+55.35D	308.5	332.0	333.6	332.0	330.8	330.5	332.1	338.6	345.8	353.3	367.2	378.9	389.4	398.1	404.8	409.7	412.8
2BS	2+55.35D	299.5	332.3	333.8	332.0	325.6	325.8	330.2	338.8	346.5	353.9	368.4	380.0	389.8	398.2	404.8	409.7	412.7
3BS	2+55.35D	299.5	331.1	332.4	333.6	334.0	335.2	338.6	346.1	353.3	360.1	372.8	383.8	392.1	399.9	405.7	410.2	412.9
4TS	3+07.65D	308.5	331.1	331.8	330.1	328.8	328.4	331.9	339.9	347.8	354.9	368.3	380.1	390.2	398.3	404.8	409.7	412.9
5S	3+19.52D	304.0	331.9	332.1	333.5	335.0	336.6	339.2	341.8	353.8	360.1	372.4	383.4	391.7	399.4	405.3	409.8	412.9
6S	2+43.48D	304.0	331.0	332.3	334.0	336.1	339.2	343.0	349.7	356.2	362.7	374.3	382.0	392.9	400.3	406.0	410.1	413.0
7TS	2+55.35D	308.5	331.0	332.2	332.9	333.4	333.4	335.7	343.5	350.7	357.9	371.1	380.3	391.8	399.5	405.7	410.0	413.0
8BS	3+07.65D	299.5	331.0	331.1	332.2	330.2	329.4	331.8	340.0	347.6	354.9	368.8	380.4	390.0	398.2	404.7	409.2	412.6
9S	3+19.52D	304.0	332.4	336.8	334.9	354.6	364.7	367.6	372.3	376.8	381.0	388.6	395.1	400.8	405.4	409.0	411.7	413.5
Tuning Fork (Upstream)																		
1	2+38.40D	296.0	331.0	333.2	336.8	342.0	346.8	350.2	356.6	362.8	368.6	378.9	387.8	395.5	401.8	406.9	410.6	413.0
2	2+30.48D	296.75	330.9	333.8	339.2	348.3	356.4	360.8	366.1	371.0	376.0	383.3	392.2	398.6	404.0	408.2	411.3	413.4
3N	2+25.48D	305.0	330.8	334.2	341.8	354.5	366.6	373.1	377.9	382.0	383.0	392.0	397.8	402.7	406.4	409.6	412.1	413.8
Tuning Fork (Downstream)																		
1	3+24.52D	296.0	330.9	333.2	336.9	342.8	348.2	351.8	358.2	364.1	369.8	380.0	388.3	396.1	402.3	407.2	410.8	413.3
2	3+32.52D	296.75	331.0	333.8	339.1	347.1	354.4	358.6	364.0	369.6	374.7	383.0	392.0	398.3	403.8	408.0	411.2	413.6
3N	3+37.52D	305.0	330.9	334.7	343.1	356.3	368.8	373.9	378.4	382.0	395.7	391.8	397.7	402.3	406.3	409.7	412.2	413.8
Floor Culvert (Left)																		
4U	2+01.00D	303.0	330.8	332.7	336.0	341.1	346.2	350.0	356.3	362.3	368.2	378.8	387.4	395.7	402.0	407.0	410.8	413.3
5U	1+13.50D		330.2	332.0	337.3	346.3	355.8	360.8	366.8	370.6	376.2	383.0	392.8	398.8	404.2	408.3	411.5	413.6
6U	0+38.50D		330.0	331.8	338.0	348.7	359.9	365.6	371.0	375.4	379.7	392.4	394.4	399.9	404.8	409.7	411.7	413.7
4D	3+62.00D		330.7	332.2	335.2	339.5	343.8	347.8	354.5	360.8	366.7	377.8	386.9	395.0	401.6	406.7	410.6	413.0
5D	4+49.50D		330.0	331.8	337.0	345.8	355.4	361.0	367.1	371.8	376.5	383.0	392.6	398.8	404.0	408.2	411.3	413.5
6D	5+24.50D		330.0	331.1	336.0	344.8	355.3	362.7	369.8	374.3	378.7	386.6	394.0	399.7	404.6	408.4	411.5	413.5
Floor Culvert (Right)																		
4U	2+01.00D	303.0	330.4	331.9	334.6	338.4	342.7	346.6	353.0	359.7	365.9	377.0	386.0	394.5	401.2	406.5	410.6	413.0
5U	1+13.50D		330.0	331.8	337.6	347.4	357.8	363.4	369.0	373.7	378.0	386.7	393.2	399.3	404.3	408.3	411.4	413.6
4D	3+62.00D		330.4	331.9	334.3	338.0	342.2	346.2	353.2	359.5	365.7	376.9	386.7	394.3	401.2	406.4	410.5	413.0
5D	4+49.50D		330.0	331.6	335.8	343.0	351.9	357.7	364.5	370.0	374.8	385.0	391.7	398.0	403.7	407.9	411.2	413.3

Table 5

Average Piezometer Readings During Filling, Type 17 Filling Arrangement, 84.5-Ft Lift

Upper Pool El 414.5, Lower Pool El 330.0, 1-Min Single (Left) Valve Operation

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water										
No.	Station	Elevation	T=15* LC=330.3**	T=30 LC=330.8	T=45 LC=332.0	T=60 LC=334.0	T=75 LC=336.5	T=90 LC=339.0	T=105 LC=341.7	T=120 LC=343.8	T=150 LC=348.3	T=180 LC=352.9	T=240 LC=361.3
Intake (Left Wall)													
1	2+42.25U	352.0	414.2	413.5	412.5	410.0	407.5	407.0	407.0	407.1	407.5	408.0	408.6
2	2+51.5U		414.3	413.5	412.1	409.0	406.5	405.1	405.3	405.5	406.0	406.5	407.4
3	2+28.25U		414.3	413.4	411.4	407.8	403.5	402.0	402.2	402.4	403.0	403.7	405.0
4	2+17.12U		414.2	413.2	410.9	406.4	399.5	398.3	398.6	398.5	398.5	399.4	402.0
5	2+05U		414.2	413.1	410.6	405.1	398.0	396.5	396.4	396.7	397.5	398.5	400.5
6	1+93U		414.2	413.0	410.0	403.0	396.4	394.6	394.5	394.9	395.9	397.0	399.0
7	1+80.5U		414.0	412.8	408.7	401.6	392.0	391.4	391.7	392.0	393.5	395.0	396.4
8	1+68.75U		414.2	412.2	408.1	400.3	391.0	390.0	390.2	390.6	392.0	393.5	395.7
9	1+56.50U		413.8	411.6	407.3	398.5	389.8	387.5	387.5	388.6	390.0	391.5	394.0
10	1+44.50U		413.9	411.5	406.6	397.0	386.4	382.5	382.5	383.0	384.0	386.5	389.9
11	2+29.5U		414.2	413.5	411.6	407.9	404.0	403.0	403.0	403.4	404.0	404.5	405.7
12	2+17.5U		414.1	413.4	411.0	406.4	401.1	399.5	399.5	399.9	400.6	401.5	403.0
13	2+05U			413.0	410.0	404.0	398.0	396.5	396.7	397.0	398.0	399.0	400.7
14	1+93.25U			412.8	409.6	403.4	396.5	393.9	394.1	394.5	395.6	396.8	398.8
15	1+80.75U			412.6	409.4	402.0	394.0	391.8	391.5	391.9	393.0	394.4	396.5
16	1+68.5U			412.0	408.6	401.0	392.7	389.0	389.2	389.9	391.0	392.5	395.0
17	1+56.25U		413.9	411.7	407.3	399.2	390.0	387.6	387.2	387.5	389.0	390.5	393.2
18	1+44.00U		413.9	411.4	406.2	396.4	386.8	384.0	384.0	384.0	386.0	387.5	390.8
19	1+18U		413.4	409.3	399.9	384.0	368.1	365.7	366.5	367.6	370.0	372.9	377.6
Filling Valve (Left Wall)													
1B	0+16.00D	304.0	411.3	406.5	396.2	378.0	361.1	358.0	359.0	360.4	363.4	366.5	371.8
2L	0+16.00D	311.0	411.4	406.4	395.4	378.3	361.0	356.3	356.9	358.1	361.0	364.5	370.0
3T	0+16.00D	318.0	411.6	406.4	395.6	376.4	357.5	354.3	355.5	356.9	360.0	363.4	369.0
4R	0+16.00D	311.0	411.8	406.6	396.2	378.7	361.1	356.2	356.8	358.0	360.9	364.3	369.9
5	0+26.00D	318.0	410.6	405.5	393.1	372.3	355.6	355.0	356.3	357.6	360.7	364.0	369.7
6	0+57.55D		329.4	315.5	306.0	319.6	348.3	350.0	351.5	353.4	356.5	360.3	366.0
7	0+67.55D		329.4	316.6	306.7	318.1	348.3	352.4	353.5	355.2	358.1	361.7	367.4
8	0+18.00D		330.0	319.0	309.8	323.9	346.1	351.0	352.5	354.1	357.4	361.0	366.8
9	0+80.00D		330.2	317.9	311.6	331.9	350.3	351.6	353.0	354.5	357.7	361.5	367.4
10B	0+88.00D	304.0	331.6	322.1	316.6	331.9	346.3	349.5	351.0	352.5	355.7	351.5	365.5
11L	0+88.00D	311.0	330.8	321.7	317.0	331.5	347.7	351.0	352.4	354.0	357.1	360.7	366.6
12T	0+88.00D	318.0	331.5	319.3	315.9	336.5	351.7	352.3	353.6	355.4	358.3	362.0	368.0
13R	0+88.00D	311.0	331.0	320.5	317.5	334.4	349.7	351.4	352.7	354.4	357.5	361.0	367.0
14	0+98.00D	303.7	332.5	325.1	318.0	325.0	335.9	339.6	341.5	343.4	347.0	351.4	358.5
15	1+21.41D	315.0	333.0	331.0	330.7	340.0	345.9	350.6	351.5	353.0	356.2	359.9	365.9
16	1+34.81D	312.0	333.4	336.4	338.0	340.2	346.0	346.7	348.4	349.9	353.2	357.0	363.5
17T	1+55.00D	298.0	333.4	336.8	339.3	340.5	347.3	348.0	349.7	351.3	354.5	358.4	364.5
18B	1+55.00D	312.0	333.9	337.3	339.7	344.0	347.3	348.0	349.9	351.3	354.5	358.4	364.5
Transition to Cross-over (Left)													
1	2+13.48D	312.0	331.9	334.7	337.5	341.0	343.7	345.3	346.8	348.5	352.0	355.9	362.4
2	2+40.98D	312.0	332.0	334.9	338.5	344.4	348.6	350.7	352.4	354.0	357.0	360.5	366.5
3	2+40.98D	296.0	332.2	335.2	338.6	344.4	349.2	351.0	352.4	354.0	357.3	360.8	366.5
Crossover Culvert													
1S	2+43.48D	304.0	332.0	337.2	344.1	373.3	391.1	397.0	398.0	399.3	400.0	401.8	403.5
2TS	2+55.35D	308.5	331.4	332.0	329.4	324.3	319.8	316.9	316.5	318.0	321.6	327.0	336.5
2BS	2+55.35D	299.5	337.6	332.2	327.9	319.0	309.8	310.5	312.7	316.0	321.0	326.8	336.6
3BS	2+55.35D	299.5	330.5	330.5	328.5	323.5	317.5	318.5	320.8	323.5	328.0	333.0	342.7
4TS	3+07.65D	308.5	330.5	330.2	326.5	319.5	313.0	311.8	314.4	317.0	327.9	327.5	337.0
5S	3+19.52D	304.0	330.1	330.0	330.4	329.6	328.7	329.8	331.5	333.5	338.1	342.9	350.5
6S	2+43.48D	304.0	330.3	331.0	330.5	329.7	328.7	330.0	331.5	334.0	337.9	342.3	350.8
7TS	2+55.35D	308.5	330.2	330.7	330.7	330.2	329.4	330.7	332.2	334.6	338.6	343.0	351.3
8BS	3+07.65D	299.5	330.1	330.7	330.7	330.0	329.6	330.7	332.4	334.5	338.5	343.1	351.1
9S	3+19.52D	304.0	331.5	334.8	338.9	347.5	354.0	356.3	357.9	359.5	362.3	365.5	371.0
Tuning Fork (Upstream)													
1	2+38.48D	296.0	330.5	331.1	331.6	332.2	332.4	333.5	335.4	337.6	341.5	345.8	354.0
2	2+30.48D	296.75	330.4	331.5	334.0	339.0	343.9	345.7	347.2	349.3	352.5	356.0	363.0
3N	2+25.48D	305.0	330.2	331.5	335.9	345.4	356.1	362.3	364.4	366.0	368.0	370.3	375.2
Tuning Fork (Downstream)													
1	3+24.52D	296.0	330.1	330.8	330.4	329.1	328.3	329.1	330.9	332.6	336.2	341.3	349.5
2	3+32.52D	296.75	330.2	330.7	330.4	329.4	328.3	329.0	331.1	331.1	337.1	341.9	350.0
3N	3+37.52D	305.0	330.2	332.3	338.0	342.9	358.4	363.9	366.2	366.9	368.5	371.9	375.8
Floor Culvert (Left)													
4U	2+01.00D	303.0	330.0	330.8	330.9	330.8	331.0	332.6	335.4	337.0	340.6	345.4	353.3
5U	1+13.50D		329.9	330.5	331.6	333.6	336.4	338.5	340.5	342.5	346.0	350.1	357.4
6U	0+38.50D		330.0	330.3	331.6	333.8	336.7	339.4	341.3	342.3	345.4	350.7	357.8
4D	3+62.00D		330.0	330.7	330.8	331.0	331.6	333.4	335.3	337.4	341.0	345.5	353.6
5D	4+49.50D		330.0	330.5	331.5	333.5	335.9	338.0	340.1	342.0	345.5	349.8	357.0
6D	5+24.50D		329.9	330.1	331.0	332.0	335.4	339.6	339.7	341.8	345.1	349.7	356.9
Floor Culvert (Right)													
4U	2+01.00D	303.0	330.0	331.0	330.7	330.3	329.4	330.9	333.0	335.0	338.0	343.9	351.4
5U	1+13.50D			330.5	332.3	336.3	341.8	345.3	346.9	349.0	352.0	356.0	362.3
4D	3+62.00D			330.8	331.5	332.5	334.0	335.5	337.1	339.0	343.0	347.5	355.1
5D	4+49.50D			330.5	332.0	334.7	339.0	342.3	344.8	346.8	350.2	354.0	361.0

(Continued)

Note: Elevations are in feet referred to mean sea level. 1-min valve schedule fills lock in 20.5 min. Bulkhead slots and air vents below filling valves closed.

* T is time (in prototype seconds) after beginning of filling operation.

** LC is elevation of water surface in lock chamber.

Table 5 (Concluded)

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water										
No.	Station	Elevation	T=300 LC=368.4	T=360 LC=375.1	T=420 LC=380.8	T=480 LC=385.9	T=540 LC=390.5	T=600 LC=394.9	T=660 LC=398.3	T=720 LC=401.8	T=840 LC=406.9	T=1020 LC=411.9	T=1200 LC=414.2
Intake (Left Wall)													
1	2+42.25U	352.0	409.3	410.0	410.4	411.0	411.4	411.7	412.0	412.5	413.1	413.6	414.1
2	2+51.5U		408.0	408.9	409.5	410.4	410.9	411.4	411.7	412.1	413.0	413.6	414.3
3	2+28.25U		406.0	407.0	408.0	409.0	409.8	410.5	411.0	411.6	412.3	413.5	414.0
4	2+17.12U		403.6	405.0	406.5	407.8	408.9	409.9	410.5	410.6	411.9	413.3	414.0
5	2+05U		402.0	403.5	405.0	406.5	407.4	408.3	409.4	410.3	411.8	413.3	
6	1+93U		400.7	402.4	404.0	405.5	407.0	407.8	409.0	410.0	411.5	413.2	
7	1+80.5U		399.0	401.0	403.1	404.4	406.5	407.2	408.5	408.6	410.9	413.0	
8	1+68.75U		398.0	400.1	402.0	403.9	405.5	406.8	408.1	409.3	411.4		
9	1+56.50U		396.5	398.9	401.0	403.0	404.8	406.3	407.6	409.0	411.0		
10	1+44.50U		392.7	395.5	398.1	400.5	402.6	404.5	406.4	407.9	410.5		414.2
11	2+29.5U		406.7	407.6	408.5	409.4	410.1	410.7	411.3	411.9	412.5	413.6	414.1
12	2+17.5U		404.3	405.5	406.6	407.6	408.6	409.5	410.1	411.0	412.1	413.5	414.0
13	2+05U		402.4	403.9	405.4	406.5	407.5	408.5	409.5	410.4	411.9	413.4	414.1
14	1+93.25U		400.5	402.4	404.0	405.4	406.6	407.7	408.9	409.3	411.6	413.2	414.0
15	1+80.75U		398.8	400.7	402.5	404.3	405.9	407.1	408.2	409.3	411.3	413.0	414.1
16	1+68.5U		397.4	399.5	401.5	403.5	405.2	406.6	407.8	409.0	411.1	413.1	414.1
17	1+56.25U		395.7	398.0	400.3	402.4	404.0	405.7	407.0	408.4	410.7	413.0	414.1
18	1+44.00U		393.6	396.2	398.7	401.0	403.0	404.8	406.4	408.0	410.4	412.8	414.0
19	1+18U		383.0	387.3	390.1	393.5	397.0	399.7	402.4	404.7	408.6	412.5	414.2
Filling Valve (Left Wall)													
1B	0+16.00D	304.0	379.0	381.8	386.0	390.0	394.0	397.3	400.4	403.1	407.7	412.5	414.2
2L	0+16.00D	311.0	375.5	380.5	383.5	389.3	393.4	396.7	399.9	402.7	407.5	412.1	414.2
3T	0+16.00D	318.0	374.5	379.6	383.5	388.9	392.8	396.2	399.5	402.5	407.4	412.0	414.2
4R	0+16.00D	311.0	375.4	380.3	383.5	389.3	393.3	396.6	399.9	402.6	407.5	412.0	414.1
5	0+26.00D	318.0	375.0	380.2	383.5	389.1	393.1	396.6	399.8	402.6	407.5	412.0	414.2
6	0+57.55D		371.7	377.1	382.0	386.4	390.9	394.5	398.0	401.0	406.3	411.2	413.7
7	0+57.55D		373.0	378.4	382.5	388.2	391.8	395.4	398.9	401.8	406.7	411.7	414.0
8	0+18.00D		372.5	377.9	382.5	387.2	391.5	395.3	398.5	401.6	406.6	411.5	414.1
9	0+80.00D		372.8	378.0	382.5	387.0	391.8	395.2	399.0	401.8	406.9	411.7	414.0
10B	0+88.00D	304.0	371.3	376.6	381.7	386.5	390.9	395.5	398.1	401.1	406.4	411.5	414.0
11L	0+88.00D	311.0	372.4	372.7	382.5	387.3	391.4	394.5	398.5	401.5	406.5	411.7	414.0
12T	0+88.00D	318.0	373.7	378.7	382.5	387.5	392.0	395.0	398.8	401.7	406.7	411.7	414.1
13R	0+88.00D	311.0	372.6	378.0	383.0	387.4	391.5	395.3	398.7	401.6	406.7	411.7	414.0
14	0+98.00D	303.7	365.1	371.4	377.0	385.0	387.7	391.8	395.7	399.2	405.2	411.2	
15	1+21.41D	315.0	371.7	377.0	382.5	386.7	391.1	395.0	398.4	401.4	406.2	411.6	
16	1+34.81D	312.0	369.5	375.1	380.5	385.5	390.0	393.0	397.5	400.6	406.0	411.5	
17T	1+55.00D	298.0	370.4	376.0	381.1	385.9	390.4	394.4	397.9	401.0	406.4	411.5	
18B	1+55.00D	312.0	370.4	376.6	381.3	385.9	390.3	394.2	397.8	400.9	406.4	411.5	
Transition to Cross-over (Left)													
1	2+13.48D	312.0	368.5	374.4	379.8	385.0	389.4	393.4	397.1	400.3	406.0	411.5	414.0
2	2+40.98D	312.0	372.3	377.5	382.5	387.2	391.4	395.0	398.5	401.4	406.6	411.7	414.2
3	2+40.98D	296.0	372.2	379.6	382.7	387.2	391.3	395.0	398.4	401.4	406.4	411.5	413.9
Crossover Culvert													
1S	2+43.48D	304.0	404.0	404.9	406.5	407.6	408.8	410.0	410.2	411.0	412.4	413.8	414.5
2TS	2+55.35D	308.5	346.2	355.0	362.9	370.3	377.2	383.0	388.7	394.1	402.3	410.1	414.0
2BS	2+55.35D	299.5	346.7	355.3	363.4	370.6	377.7	384.0	389.1	394.0	402.0	410.0	413.9
3BS	2+55.35D	299.5	350.7	359.0	366.6	373.4	380.0	385.5	390.5	395.3	402.9	410.5	414.0
4TS	3+07.65D	308.5	346.0	355.0	363.0	370.5	377.3	384.0	388.8	393.9	402.1	410.0	
5S	3+19.52D	304.0	358.4	365.3	372.0	378.0	384.5	387.9	393.0	397.0	404.0	410.9	
6S	2+43.48D	304.0	358.2	365.5	372.0	378.0	383.5	388.5	393.2	397.2	404.1	411.0	
7TS	2+55.35D	308.5	358.7	365.9	372.4	378.3	383.0	388.9	393.4	397.4	404.2	411.0	414.1
8BS	3+07.65D	299.5	358.8	365.8	372.4	378.3	383.0	388.5	393.3	397.3	404.1	411.0	414.1
9S	3+19.52D	304.0	376.1	384.0	385.8	389.7	393.5	397.0	400.0	403.5	407.5	412.1	414.2
Tuning Fork (Upstream)													
1	2+38.48D	296.0	360.7	367.5	374.0	379.7	384.0	389.6	394.0	398.0	404.5	411.1	414.2
2	2+30.48D	296.75	368.7	374.5	380.0	383.0	389.3	393.4	397.0	400.5	406.0	411.5	414.3
3N	2+25.48D	305.0	380.2	384.0	387.5	391.2	394.9	398.0	400.5	403.4	407.9	412.2	414.3
Tuning Fork (Downstream)													
1	3+24.52D	296.0	357.6	364.4	371.1	377.5	383.5	387.9	392.7	396.7	404.0	410.8	414.0
2	3+32.52D	296.75	359.6	364.9	371.5	377.5	383.5	387.9	393.0	397.3	403.9	410.8	414.1
3N	3+37.52D	305.0	380.3	384.0	388.5	392.0	395.4	398.0	400.0	403.7	408.0	412.0	414.0
Floor Culvert (Left)													
4U	2+01.00D	303.0	360.5	367.4	373.5	379.4	384.0	389.7	394.1	398.0	404.5	411.0	414.2
5U	1+13.50D		364.0	370.5	376.4	381.7	386.9	391.4	395.4	399.0	405.2	411.3	414.3
6U	0+38.50D		364.4	370.7	376.5	382.0	387.0	391.1	395.2	399.0	405.0	411.2	414.1
4D	3+62.00D		360.8	367.4	373.9	379.5	384.0	389.7	394.1	398.0	404.5	411.0	414.0
5D	4+49.50D		363.9	370.3	376.2	381.5	386.5	391.0	395.1	398.9	405.0	411.2	414.1
6D	5+24.50D		363.7	370.1	376.1	381.4	386.5	390.9	395.0	398.7	404.9	411.0	414.1
Floor Culvert (Right)													
4U	2+01.00D	303.0	359.0	365.9	372.3	378.1	384.0	389.0	393.2	397.6	404.0	410.9	414.1
5U	1+13.50D		368.4	374.2	379.5	385.0	389.0	393.0	396.8	400.2	405.8	411.5	414.2
4D	3+62.00D		362.1	368.5	375.0	380.4	385.7	390.2	394.5	398.3	404.6	411.1	414.1
5D	4+49.50D		367.3	373.3	378.8	384.0	388.4	392.6	396.5	399.8	405.7	411.4	414.3

Table 6

Average Piezometer Readings During Emptying, Type 17 Emptying Arrangement, 84.5-Ft Lift

Upper Pool El 414.5, Lower Pool El 330.0, Normal 2-Min Valve Operation

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water								
No.	Station	Elevation	T=15* LC=414.3**	T=30 LC=414.0	T=45 LC=413.4	T=60 LC=412.6	T=75 LC=411.0	T=90 LC=409.4	T=120 LC=405.2	T=150 LC=400.0	T=180 LC=395.0
Floor Culvert (Left)											
4U	2+01.00D	303.0	414.0	413.0	411.7	407.5	403.5	395.8	385.4	376.6	372.4
5U	1+13.50D		414.2	413.8	413.0	410.5	408.3	404.6	396.8	389.6	384.0
6U	0+38.50D		414.2	414.0	413.4	411.5	409.5	406.5	399.4	392.0	387.0
4D	3+62.00D		414.1	413.3	411.7	406.9	402.4	395.8	382.4	371.6	368.0
5D	4+49.50D		414.2	414.0	413.3	410.7	408.3	404.8	397.0	388.9	384.0
6D	5+24.50D		414.2	414.0	413.6	411.8	410.0	407.4	400.4	392.6	387.0
Floor Culvert (Right)											
4U	2+01.00D	303.0	414.1	413.3	411.9	408.0	404.3	399.0	387.3	379.0	374.4
5U	1+13.50D		414.2	413.9	413.1	411.0	408.8	405.6	398.3	391.2	386.0
4D	3+62.00D		414.1	413.3	411.8	407.4	402.8	395.6	379.8	368.7	364.7
5D	4+49.50D		414.2	414.0	413.3	411.0	408.8	405.8	396.8	368.8	384.0
Tuning Fork (Upstream)											
1	2+38.48D	296.0	414.0	413.0	411.7	408.7	404.1	398.0	385.7	383.0	373.4
2	2+30.48D	296.75	414.0	413.0	412.0	409.2	405.7	400.0	389.5	382.0	377.4
3N	2+25.48D	305.0	414.0	413.0	412.0	409.3	405.9	400.6	390.2	383.0	377.0
Tuning Fork (Downstream)											
1	3+24.52D	296.0	413.7	412.5	410.8	405.7	400.7	393.4	378.0	368.2	364.7
2	3+32.52D	296.75	413.7	412.2	410.5	404.9	399.7	392.0	376.2	367.0	363.5
3N	3+37.52D	305.0	413.5	411.7	410.3	404.3	398.7	390.8	374.7	366.6	363.1
Crossover Culvert											
1S	2+43.48D	304.0	413.7	412.0	410.4	404.5	399.0	391.3	375.0	366.8	363.3
2TS	2+55.35D	308.0	413.5	411.9	410.4	404.4	398.9	391.3	375.8	366.0	363.3
2BS	2+55.35D	299.5	413.5	411.9	410.4	404.5	399.0	391.3	374.7	366.6	363.3
3BS	2+55.35D	299.5	413.8	412.0	410.0	402.9	396.0	386.5	363.2	353.7	351.3
4TS	3+07.65D	308.5	413.8	411.9	409.5	400.5	391.8	380.0	353.8	340.8	338.6
5S	3+19.52D	304.0	414.0	413.0	412.0	408.7	405.7	401.0	390.0	383.0	378.2
6S	2+43.48D	304.0		413.0	412.0	410.0	406.8	402.2	393.2	386.2	381.0
7TS	2+55.35D	308.5		412.5	410.4	405.4	397.8	387.7	369.0	357.3	354.4
8BS	3+07.65D	299.5		412.5	410.3	404.1	394.5	383.0	354.8	339.8	338.1
9S	3+19.52D	304.8	413.4	411.0	408.8	401.8	392.0	378.5	356.2	346.2	344.0
Transition and Left Culvert											
1T	3+22.02D	312.0	413.6	411.7	409.8	404.3	396.7	386.7	364.5	352.0	349.7
2B	3+22.02D	296.0	413.4	411.7	409.7	404.0	395.8	383.0	363.0	351.3	349.4
3B	4+04.52D	298.0	413.0	410.7	408.6	402.0	393.0	380.7	357.7	346.5	345.0
4L	4+04.52D	305.0	412.5	410.0	408.0	400.7	391.1	378.0	354.7	346.0	344.7
5T	4+04.52D	312.0	412.6	410.0	408.0	401.0	391.3	378.C	354.8	346.0	344.8
6R	4+04.52D	305.0	413.0	410.2	408.6	401.8	393.0	380.8	357.2	346.1	344.8
Emptying Valve (Left)											
1B	4+82.52D	298.0	411.9	409.0	406.9	398.7	388.0	375.0	357.5	343.6	342.5
2L	4+82.52D	305.0	411.5		406.7	398.1	387.0	374.2	351.0	343.6	342.5
3T	4+82.52D	312.0	411.9		407.0	398.3	388.1	374.9	351.5	343.8	342.7
4R	4+82.52D	305.0	411.9		407.0	398.7	388.5	374.5	351.0	343.6	342.5
5	5+14.02D	312.0	428.5	322.4	316.4	309.8	306.0	338.0	333.0	341.7	340.5
6B	5+24.02D	298.0	328.9	321.8	314.5	308.0	303.7	304.4	324.0	341.2	340.4
7L	5+24.02D	305.0	327.2	320.0	313.3	306.7	303.0	303.5	332.0	340.8	339.7
8T	5+24.02D	312.0	327.9	320.0	314.0	306.9	302.9	304.0	331.1	341.5	340.5
9R	5+24.02D	305.0	327.8	321.3	314.7	308.5	304.7	305.4	331.8	341.7	340.6
10	5+34.02D	312.0	327.7	320.4	314.7	307.7	303.7	306.9	337.1	341.0	340.0
11	5+39.02D		328.7	319.1	314.6	307.7	305.7	312.2	340.7	341.0	339.9
12	5+44.02D		329.0	320.0	315.4	310.0	309.0	316.5	341.0	341.0	339.8
13	5+49.02D		331.5	321.6	316.4	312.0	311.5	320.0	340.6	340.8	339.8
14	5+54.02D		331.9	321.8	318.0	314.5	315.0	324.5	340.8	340.8	339.7
Culvert and Left Outlet											
1B	6+12.00D	298.0	331.4	332.0	332.4	334.0	335.7	337.7	340.1	339.8	338.8
2L	6+12.00D	305.0	331.7	332.0	332.5	334.0	335.0	337.0	338.5	338.0	337.4
3T	6+12.00D	312.0	331.5	331.9	332.7	334.4	335.5	337.2	338.6	338.0	337.1
4R	6+12.00D	305.0	331.6	331.8	332.4	334.1	335.0	336.7	338.5	338.0	337.0
5B	6+47.00D	298.0	331.0	331.5	332.2	334.0	335.3	336.2	337.5	337.0	336.1
6T	6+47.00D	205.0	330.9	331.4	332.0	333.7	335.1	336.1	337.4	337.0	336.3
7L	6+47.00D	312.0	331.0	331.5	332.3	334.2	335.6	337.0	338.6	338.0	337.3
8R	6+47.00D	305.0	331.0	331.5	332.3	334.0	335.2	336.4	337.4	337.0	336.4
9	7+30.75D	298.0	330.0	330.6	331.4	333.7	334.2	335.6	337.2	337.0	336.6
10	7+30.75D	298.0	330.0	330.5	331.5	333.0	334.7	336.8	338.7	339.0	338.4
11	7+30.75D	298.0	330.0	330.4	331.4	333.0	335.4	338.4	343.5	344.0	343.6
Culvert (Right)											
12B	6+47.00D	298.0	330.6	331.3	332.1	333.3	334.3	336.0	337.0	336.4	335.7
13L	6+47.00D	305.0	330.7	331.5	332.3	333.7	334.7	336.6	337.6	337.5	336.8
14T	6+47.00D	312.0	330.5	331.3	332.0	333.5	334.7	336.6	337.6	337.4	336.7
15R	6+47.00D	305.C	330.5	331.2	331.9	333.0	334.5	336.5	337.8	337.7	336.9

(Continued)

Note: Elevations are in feet referred to mean sea level. 2-min valve schedule empties lock in 13.3 min. Bulkhead slots and air vents below emptying valves closed.

* T is time (in prototype seconds) after beginning of emptying operation.

** LC is elevation of water surface in lock chamber.

Table 6 (Concluded)

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water								
No.	Station	Elevation	T=240 LC=385.0	T=300 LC=375.8	T=360 LC=367.1	T=420 LC=358.6	T=480 LC=351.5	T=540 LC=345.0	T=600 LC=339.8	T=660 LC=335.8	T=720 LC=332.8
Floor Culvert (Left)											
4U	2+01.00D	303.0	365.3	359.0	352.8	347.4	342.7	338.7	335.7	333.0	331.3
5U	1+13.50D	↓	375.4	367.0	359.0	352.4	346.0	341.1	337.3	334.0	331.8
6U	0+38.50D	↓	376.9	368.5	360.2	353.4	347.0	342.0	337.8	334.4	331.9
4D	3+62.00D	↓	361.2	355.8	350.5	346.0	341.3	337.9	335.0	332.6	331.0
5D	4+49.50D	↓	374.4	366.4	358.8	352.3	346.1	341.2	337.3	334.1	331.7
6D	5+24.50D	↓	377.5	369.1	361.0	354.1	347.8	342.4	338.1	334.9	332.1
Floor Culvert (Right)											
4U	2+01.00D	303.0	366.7	360.0	353.7	348.4	343.3	339.3	335.8	333.2	331.2
5U	1+13.50D	↓	376.0	367.7	359.5	353.0	346.7	341.7	337.5	334.2	331.8
4D	3+62.00D	↓	360.4	354.3	349.0	344.5	340.7	337.4	334.6	332.6	331.0
5D	4+49.50D	↓	375.0	366.8	358.9	352.4	346.2	341.4	337.4	334.2	331.8
Tuning Fork (Upstream)											
1	2+38.48D	296.0	366.1	359.4	353.2	348.0	343.4	339.1	336.0	333.3	331.4
2	2+30.48D	296.75	369.5	362.3	355.5	349.6	344.3	339.9	336.5	333.6	331.4
3N	2+25.48D	303.0	369.5	362.1	355.7	349.6	344.3	340.0	336.7	333.7	331.4
Tuning Fork (Downstream)											
1	3+24.52D	296.0	359.0	353.0	348.7	344.4	340.5	337.4	334.7	332.5	331.0
2	3+32.52D	296.75	358.1	352.8	348.3	344.0	340.3	337.0	334.7	332.5	331.0
3N	3+37.52D	305.0	357.5	352.6	348.3	344.4	340.4	337.4	334.9	332.7	331.3
Crossover Culvert											
1S	2+43.48D	304.0	357.7	352.5	348.0	343.8	340.0	336.8	334.5	332.4	330.8
2TS	2+55.35D	308.0	357.6	351.8	347.8	343.7	339.9	336.8	334.5	332.4	331.0
2BS	2+55.35D	299.5	357.7	352.5	348.0	343.8	340.0	336.8	334.6	332.4	331.0
3BS	2+55.35D	299.5	347.7	344.6	341.9	339.0	336.6	334.5	333.0	331.5	330.5
4TS	3+07.65D	308.5	338.3	337.5	335.8	334.3	333.1	331.9	331.0	330.4	329.7
5S	3+19.52D	304.0	370.0	362.7	355.2	349.4	343.8	339.5	336.0	333.5	331.4
6S	2+43.48D	304.0	372.5	365.0	357.9	351.0	345.6	340.7	337.0	333.8	331.7
7TS	2+55.35D	308.5	350.0	346.9	343.5	340.4	337.5	335.0	333.3	331.6	330.5
8BS	3+07.65D	299.5	338.0	336.6	335.4	334.3	333.0	332.0	331.1	330.5	329.8
9S	3+19.52D	304.8	342.8	340.7	338.5	336.1	334.5	333.0	331.8	331.0	330.2
Transition and Left Culvert											
1T	3+22.02D	312.0	347.0	343.9	341.0	338.5	336.1	334.1	332.6	331.5	330.4
2B	3+22.02D	296.0	346.5	343.3	340.7	338.1	335.9	334.0	332.6	331.4	330.4
3B	4+04.52D	298.0	343.0	340.5	338.5	336.6	334.7	333.3	332.1	331.1	330.4
4L	4+04.52D	305.0	↓	↓	↓	↓	↓	333.3	↓	331.1	330.3
5T	4+04.52D	312.0	↓	↓	↓	↓	↓	333.1	↓	331.0	330.3
6R	4+04.52D	305.0	↓	↓	↓	↓	↓	333.2	↓	331.0	330.3
Emptying Valve (Left)											
1B	4+82.52D	298.0	341.0	339.0	337.0	335.6	334.0	332.6	331.7	331.0	330.3
2L	4+82.52D	305.0	↓	↓	↓	↓	↓	↓	331.7	↓	↓
3T	4+82.52D	312.0	↓	↓	↓	↓	↓	↓	331.7	↓	↓
4R	4+82.52D	305.0	↓	↓	↓	↓	↓	↓	331.8	↓	↓
5	5+14.02D	312.0	339.5	337.6	336.2	334.8	333.5	332.4	331.5	330.8	330.0
6B	5+24.02D	298.0	339.0	337.5	336.0	334.6	↓	332.4	↓	330.8	330.2
7L	5+24.02D	305.0	338.8	337.2	335.9	334.5	↓	332.4	↓	330.8	330.0
8T	5+24.02D	312.0	339.5	337.5	336.2	334.7	↓	332.2	↓	330.7	330.2
9R	5+24.02D	305.0	339.5	337.6	336.3	334.8	↓	332.4	↓	331.0	330.3
10	5+34.02D	312.0	339.5	337.4	336.0	334.6	333.4	332.3	↓	331.0	330.0
11	5+39.02D	↓	339.0	337.3	335.9	334.5	333.3	332.2	↓	330.9	329.9
12	5+44.02D	↓	338.8	337.0	335.7	↓	333.0	332.0	331.4	330.8	330.2
13	5+49.02D	↓	338.7	337.0	335.8	↓	333.2	332.1	331.5	330.8	330.2
14	5+54.02D	↓	338.7	337.0	335.8	↓	333.1	332.1	331.5	330.8	330.2
Culvert and Left Outlet											
1B	6+12.00D	298.0	337.8	336.3	335.0	334.0	332.7	332.0	331.4	330.7	330.2
2L	6+12.00D	305.0	336.8	335.4	334.5	333.6	332.5	331.7	331.1	330.6	330.1
3T	6+12.00D	312.0	336.6	335.5	334.5	333.6	332.5	↓	331.1	330.7	↓
4R	6+12.00D	305.0	336.5	335.4	334.5	333.6	332.5	↓	331.0	↓	↓
5B	6+47.00D	298.0	335.7	334.8	334.0	333.3	332.3	↓	330.9	↓	↓
6T	6+47.00D	305.0	335.8	334.8	334.0	333.3	332.3	331.5	331.0	↓	330.2
7L	6+47.00D	312.0	336.5	335.4	334.5	333.7	333.5	331.8	331.2	330.8	330.2
8R	6+47.00D	305.0	335.8	334.7	334.0	333.1	333.3	331.5	331.0	330.6	330.1
9	7+30.75D	298.0	336.0	334.7	334.0	333.3	333.4	331.5	331.0	330.7	330.4
10	7+30.75D	298.0	337.6	336.0	335.0	333.8	333.8	332.0	331.4	330.8	330.5
11	7+30.75D	298.0	341.8	339.4	337.7	336.0	333.4	333.0	332.0	331.3	330.6
Culvert (Right)											
12B	6+47.00D	298.0	335.2	334.5	334.0	332.8	332.2	331.5	331.0	330.5	330.2
13L	6+47.00D	305.0	336.1	335.0	334.4	333.3	332.5	331.7	331.0	330.5	330.2
14T	6+47.00D	312.0	336.0	335.0	334.3	333.1	332.5	331.5	331.0	330.5	330.1
15R	6+47.00D	305.0	336.2	335.2	334.5	333.3	332.5	331.5	331.1	330.5	330.2

Table 7

Average Piezometer Readings During Emptying, Type 17 Emptying Arrangement, 84.5-Ft Lift

Upper Pool El 414.5, Lower Pool El 330.0, 2-Min Single (Left) Valve Operation

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water										
			T=15*	T=30	T=45	T=60	T=75	T=90	T=105	T=120	T=150	T=180	T=240
No.	Station	Elevation	LC=414.3**	LC=414.2	LC=414.0	LC=413.8	LC=413.1	LC=412.2	LC=411.1	LC=410.0	LC=407.3	LC=404.9	LC=399.0
Floor Culvert (Left)													
4U	2+01.00D	303.0	414.2	413.7	413.3	412.0	410.2	408.0	404.9	401.5	397.4	394.2	388.8
5U	1+13.50D	↓	414.3	414.1	413.6	412.9	411.7	410.3	408.4	406.0	402.0	398.6	393.0
6U	0+38.50D	↓	414.3	414.7	413.8	413.3	412.3	411.1	409.4	407.2	403.3	399.7	394.0
4D	3+62.00D	↓	414.2	413.6	412.1	411.8	410.0	407.8	404.9	401.5	397.5	394.0	388.5
5D	4+49.50D	↓	414.3	414.7	413.8	413.0	411.9	410.4	408.6	406.4	402.5	399.0	393.2
6D	5+24.50D	↓	414.2	414.1	413.8	412.4	412.5	411.4	409.6	407.6	403.9	400.2	394.3
Floor Culvert (Right)													
4U	2+01.00D	303.0	414.2	413.6	413.3	412.2	410.5	408.5	405.6	402.5	398.1	394.6	389.4
5U	1+13.50D	↓	414.3	414.7	413.7	413.0	412.0	410.7	408.9	406.6	408.9	399.1	393.3
4D	3+62.00D	↓	414.2	413.7	413.2	412.0	410.0	407.9	404.8	401.4	396.4	393.0	388.0
5D	4+49.50D	↓	414.3	414.1	413.7	413.2	412.0	410.7	408.9	406.8	402.8	399.1	393.5
Tuning Fork (Upstream)													
1	2+38.48D	296.0	414.1	413.5	412.8	411.4	409.3	406.1	401.7	397.5	393.4	391.0	387.4
2	2+30.48D	296.75	414.3	413.7	413.2	412.2	410.6	408.4	405.5	402.5	399.0	396.0	390.3
3N	2+25.48D	305.0	414.2	413.7	413.2	412.3	410.9	408.7	406.0	403.1	399.5	396.5	390.8
Tuning Fork (Downstream)													
1	3+24.52D	296.0	413.8	412.9	411.5	408.7	404.5	399.3	392.0	385.5	377.5	374.9	371.0
2	3+32.52D	296.75	413.7	412.7	411.2	408.1	403.4	397.7	390.0	383.0	375.7	373.5	369.9
3N	3+37.52D	305.0	413.6	412.5	411.0	407.9	403.0	396.2	389.5	382.5	375.7	373.8	370.6
Crossover Culvert													
1S	2+43.48D	304.0	413.7	412.5	411.2	407.8	403.1	397.7	389.6	382.5	375.5	373.0	370.0
2TS	2+55.35D	308.0	413.7	↓	411.0	407.7	402.8	397.3	389.6	382.5	374.3	372.0	369.6
2BS	2+55.35D	299.5	413.6	↓	411.0	407.8	403.0	397.3	389.5	381.8	375.3	373.0	369.8
3BS	2+55.35D	299.5	413.9	↓	410.5	406.5	400.3	392.4	381.5	369.4	359.5	359.0	356.9
4TS	3+07.65D	308.5	414.0	↓	409.8	403.6	394.0	383.5	368.5	353.0	340.3	337.7	336.0
5S	3+19.54D	304.0	414.7	413.3	411.8	407.9	401.5	395.0	380.3	364.1	365.3	362.7	353.3
6S	2+43.48D	304.0	414.1	413.0	411.6	409.0	404.7	395.0	389.5	380.3	374.2	372.2	368.8
7TS	2+55.35D	308.5	414.0	413.5	413.1	412.1	410.7	408.5	406.2	403.5	400.1	397.3	391.4
8BS	3+07.65D	299.5	414.0	413.5	413.0	412.0	410.6	408.5	406.1	403.7	400.2	397.1	391.3
9S	3+19.52D	304.0	413.5	411.4	408.6	402.8	394.4	384.0	369.4	357.8	351.4	350.1	348.6
Transition and Left Culvert													
1T	3+22.02D	312.0	413.8	412.1	410.0	405.8	399.0	389.6	377.5	365.9	356.7	354.5	351.7
2B	3+22.02D	296.0	413.7	411.8	409.6	405.0	397.8	388.0	375.6	364.4	356.3	355.0	352.8
3B	4+04.52D	298.0	413.0	411.0	408.2	403.0	394.6	384.0	370.1	358.3	350.5	349.5	347.8
4L	4+04.52D	305.0	412.6	410.7	407.6	402.0	393.5	382.2	367.3	355.7	350.0	349.1	347.4
5T	4+04.52D	312.0	412.6	410.7	407.7	402.0	393.5	381.8	367.4	355.7	350.0	349.2	347.4
6R	4+04.52D	305.0	413.1	410.9	408.1	402.9	394.6	383.0	369.7	357.7	350.0	348.9	347.1
Emptying Valve (Left)													
1B	4+82.52D	298.0	411.7	410.3	405.8	399.5	389.8	377.5	362.7	351.5	347.0	346.3	344.9
2L	4+82.52D	305.0	411.5	↓	405.5	399.4	389.7	377.0	362.3	351.3	346.9	346.2	344.8
3T	4+82.52D	312.0	411.5	↓	405.8	399.5	390.0	377.5	363.0	351.6	347.1	346.4	344.9
4R	4+82.52D	305.0	411.9	↓	406.1	400.0	390.5	377.5	362.8	351.5	346.7	346.0	344.7
5	5+14.02D	312.0	328.2	320.5	314.0	308.0	303.3	305.6	317.0	337.4	344.3	343.5	342.5
6B	5+24.02D	298.0	328.9	319.7	312.4	305.4	301.0	302.2	310.4	327.7	342.7	341.8	341.0
7L	5+24.02D	305.0	326.8	318.5	311.1	303.8	299.5	300.6	312.4	338.9	343.0	342.3	341.5
8T	5+24.02D	312.0	327.5	318.6	311.4	304.9	299.5	302.0	312.4	339.8	344.0	343.2	342.1
9R	5+24.02D	305.0	327.5	318.7	312.0	306.2	301.4	303.3	314.5	338.5	344.1	343.4	342.4
10	5+34.02D	312.0	328.0	318.8	312.3	306.1	300.8	303.8	320.8	341.3	343.2	342.5	341.7
11	5+39.02D	↓	328.2	318.7	313.0	307.0	302.3	308.9	328.0	343.7	343.3	342.5	341.8
12	5+44.02D	↓	329.5	319.8	314.1	308.5	306.0	312.5	331.7	343.4	343.0	342.4	341.6
13	5+49.02D	↓	331.0	321.0	315.1	310.7	311.0	317.0	333.5	343.0	343.0	342.4	341.5
14	5+54.02D	↓	332.0	321.0	316.4	313.0	315.6	321.3	335.4	343.3	343.0	342.3	341.5
Culvert and Left Outlet													
1B	6+12.00D	298.0	331.4	332.0	331.9	333.5	335.7	338.0	339.5	341.9	341.9	341.3	340.5
2L	6+12.00D	305.0	331.6	332.1	331.9	333.5	335.5	337.0	338.1	339.8	339.4	339.0	338.5
3T	6+12.00D	312.0	331.5	332.0	332.2	333.2	335.5	337.4	338.1	339.6	339.2	338.7	338.3
4R	6+12.00D	305.0	331.5	331.9	332.0	333.4	334.9	336.7	337.8	339.5	339.0	338.5	338.1
5B	6+47.00D	298.0	331.0	331.7	332.4	333.4	334.7	336.4	337.0	338.0	338.1	339.5	337.1
6T	6+47.00D	305.0	331.0	331.5	332.4	333.4	334.7	336.3	337.6	338.3	338.2	337.7	337.5
7L	6+47.00D	312.0	330.9	331.5	332.5	333.6	335.3	337.2	338.3	339.5	339.3	339.0	338.4
8R	6+47.00D	305.0	331.1	331.7	332.5	333.6	335.0	336.5	337.3	338.4	338.1	337.5	337.2
9	7+30.75D	298.0	330.0	330.8	331.5	332.5	334.0	335.5	336.8	338.1	338.2	337.8	337.5
10	7+30.75D	298.0	330.0	330.7	331.5	332.5	334.4	336.4	338.5	340.3	340.7	340.3	339.7
11	7+30.75D	298.0	330.0	330.5	331.5	333.2	335.9	339.4	343.9	347.1	348.1	347.0	345.9
Culvert (Right)													
12B	6+47.00D	298.0	--	--	--	--	--	--	--	--	--	--	--
13L	6+47.00D	305.0	--	--	--	--	--	--	--	--	--	--	--
14T	6+47.00D	312.0	--	--	--	--	--	--	--	--	--	--	--
15R	6+47.00D	305.0	--	--	--	--	--	--	--	--	--	--	--

(Continued)

Note: Elevations are in feet referred to mean sea level. 2-min valve schedule empties lock in 24.6 min. Bulkhead slots and air vents below emptying valves closed.

* T is time (in prototype seconds) after beginning of emptying operation.

** LC is elevation of water surface in lock chamber.

Table 7 (Concluded)

Piezometer Locations: No.	Station	Elevation	Average Piezometer Readings in Prototype Feet of Water: T=300 LC=313.0	T=360 LC=388.1	T=420 LC=383.0	T=480 LC=378.0	T=540 LC=373.2	T=600 LC=368.7	T=660 LC=364.0	T=840 LC=351.8	T=1020 LC=342.0	T=1260 LC=333.3	T=1500 LC=329.7
Floor Culvert (Left)													
4U	2+01.00D	303.0	383.5	377.9	372.9	368.5	364.1	360.0	356.4	346.0	338.7	332.3	329.5
5U	1+13.50D		387.1	381.5	376.0	371.5	366.5	362.1	353.0	347.3	339.4	332.5	329.5
6U	0+38.50D		387.8	382.0	376.5	372.0	367.0	362.7	353.6	347.6	339.7	332.7	329.6
4D	3+62.00D		383.4	377.9	373.0	368.6	363.9	360.0	356.0	346.0	338.8	332.3	329.5
5D	4+49.50D		387.4	381.7	376.0	371.6	366.6	362.5	353.3	347.4	339.5	332.5	329.6
6D	5+24.50D		388.3	382.0	377.1	372.5	367.5	363.1	359.0	347.9	339.8	332.5	329.5
Floor Culvert (Right)													
4U	2+01.00D	303.0	383.5	378.8	374.5	369.4	364.3	360.6	356.7	346.4	339.0	332.3	329.5
5U	1+13.50D		387.5	381.8	376.4	392.0	366.7	362.6	358.5	347.4	339.5	332.5	329.5
4D	3+62.00D		383.4	377.6	372.5	368.5	363.7	359.6	356.0	346.0	338.7	332.3	329.5
5D	4+49.50D		387.5	381.8	396.4	372.0	366.8	362.5	358.4	347.5	339.6	332.5	329.6
Tuning Fork (Upstream)													
1	2+38.48D	296.0	380.2	375.1	371.0	366.8	362.4	358.9	355.0	345.9	338.5	332.4	330.0
2	2+30.48D	296.75	383.0	379.3	374.4	369.7	365.6	361.0	357.0	347.1	339.3	332.1	330.0
3N	2+25.48D	305.0	383.0	379.7	374.9	370.3	365.5	361.2	357.1	347.3	339.3	332.1	329.9
Tuning Fork (Downstream)													
1	3+24.52D	296.0	366.9	363.8	360.0	357.0	353.9	351.0	345.2	341.4	336.1	331.5	329.6
2	3+32.52D	296.75	366.0	363.0	359.4	356.4	353.4	350.5	347.7	341.1	336.0	331.5	329.7
3N	3+37.52D	305.0	366.5	363.5	359.8	356.7	353.6	357.0	346.2	341.4	336.1	331.7	329.8
Crossover Culvert													
1S	2+43.48D	304.0	365.7	362.5	359.1	356.0	353.1	350.1	347.5	340.8	335.8	331.5	329.6
2TS	2+55.35D	308.0	365.5	362.7	358.9	355.7	353.0	350.5	347.5	341.0	335.8	331.5	329.7
2BS	2+55.35D	299.5	365.5	362.7	359.0	356.1	352.9	350.3	347.6	341.0	335.8	331.6	329.7
3BS	2+55.35D	299.5	354.7	352.2	349.6	347.5	346.2	344.3	342.5	338.0	334.2	331.0	329.5
4TS	3+07.65D	308.5	337.8	338.2	337.1	337.0	335.9	335.0	334.6	332.6	331.3	330.0	329.5
5S	3+19.52D	304.0	354.5	349.1	356.9	347.5	345.8	345.5	345.1	335.5	334.0	330.9	329.5
6S	2+43.48D	304.0	365.0	362.4	358.1	357.0	353.4	353.8	348.5	342.1	336.4	331.8	329.9
7TS	2+55.35D	308.5	385.8	380.4	375.2	370.6	366.0	361.5	357.5	347.3	339.5	332.5	
8BS	3+07.65D	299.5	385.6	380.2	375.0	370.4	365.8	361.5	357.5	347.2	339.4	332.5	
9S	3+19.52D	304.0	346.7	345.1	343.3	342.1	340.6	339.0	338.1	335.1	332.9	330.7	
Transition and Left Culvert													
1T	3+22.02D	312.0	350.0	348.2	346.4	344.7	343.3	341.8	340.2	336.5	333.6	331.0	329.8
2B	3+22.02D	296.0	351.0	348.8	347.0	345.0	343.5	342.0	340.5	336.6	333.5	331.0	329.8
3B	4+04.52D	298.0	346.4	344.5	343.2	341.9	340.8	339.2	338.4	335.4	332.8	330.8	329.9
4L	4+04.52D	305.0	345.9	344.4	343.0	341.5	340.5	339.1	338.7				329.8
5T	4+04.52D	312.0	346.0	344.5	343.0	341.5	340.6	339.1	338.2				329.8
6R	4+04.52D	305.0	345.7	344.4	342.9	341.5	340.4	339.1	338.1				329.9
Emptying Valve (Left)													
1B	4+82.52D	298.0	343.5	342.3	341.0	339.9	339.0	338.0	337.0	334.6	332.4	330.5	329.9
2L	4+82.52D	305.0	343.5	342.3		339.8	339.8			334.7		330.5	329.9
3T	4+82.52D	312.0	343.7	342.4		340.0	339.0			334.7		330.6	330.0
4R	4+82.52D	305.0	343.5	342.2		339.7	338.9			334.6		330.6	330.0
5	5+14.02D	312.0	341.5	340.5	339.4	338.4	337.6	337.0	336.0	334.0	332.0	330.5	329.9
6B	5+24.02D	298.0	340.0	339.9	338.4	337.5	337.0	336.1	335.4	333.9		330.5	329.9
7L	5+24.02D	305.0	340.7	340.0	338.6	337.7	337.2	336.5	335.5			330.5	330.0
8T	5+24.02D	312.0	341.4	340.4	339.0	338.2	337.5	336.8	335.7			330.4	329.8
9R	5+24.02D	305.0	341.4	340.4	339.1	338.2	337.5	336.8	335.9			330.5	329.8
10	5+34.02D	312.0	340.9	340.0	338.8	337.9	337.1	336.5	335.6				330.0
11	5+39.02D		340.9	340.0	338.7	337.9	337.1	336.5	335.5				330.0
12	5+44.02D		340.6	339.8	338.5	337.5	337.0	336.7	335.4	333.5			329.9
13	5+49.02D		340.5	339.9	338.5	337.5	337.0	336.3	335.4	333.8			330.0
14	5+54.02D		340.6	339.9	338.5	337.5	337.0	336.3	335.4	333.8			330.0
Culvert and Left Outlet													
1B	6+12.00D	298.0	339.5	338.9	337.8	337.0	336.4	335.6	335.0	333.3	331.6	330.4	329.9
2L	6+12.00D	305.0	338.0	337.4	336.4	325.8	335.3	334.8	334.2	333.0	331.5	330.4	330.0
3T	6+12.00D	312.0	337.7	336.9	335.8	335.5	335.0	334.8	334.4	333.1	332.0	330.8	330.2
4R	6+12.00D	305.0	337.5	337.0	336.0	335.5	335.0	334.5	334.0	332.5	331.3	330.3	329.9
5B	6+47.00D	298.0	336.6	336.1	335.4	334.9	334.5	334.0	333.7	332.5	331.3	330.4	330.0
6T	6+47.00D	305.0	336.5	336.3	335.5	335.0	334.7	334.1	333.8	332.4	331.3		330.0
7L	6+47.00D	312.0	337.6	337.1	336.4	335.7	335.3	334.7	334.1	332.8	331.5		329.9
8R	6+47.00D	305.0	336.1	336.2	335.4	335.0	334.6	334.1	333.7	332.5	331.3		330.0
9	7+30.75D	298.0	336.8	336.2	335.9	335.0	334.6	334.1	333.7	332.5	331.4		
10	7+30.75D	298.0	338.7	338.0	337.4	336.7	336.0	335.4	334.8	333.0	331.7	330.5	
11	7+30.75D	298.0	344.5	343.0	341.7	340.4	339.4	338.3	337.1	334.5	332.5	330.8	
Culvert (Right)													
12B	6+47.00D	298.0	--	--	--	--	--	--	--	--	--	--	--
13L	6+47.00D	305.0	--	--	--	--	--	--	--	--	--	--	--
14T	6+47.00D	312.0	--	--	--	--	--	--	--	--	--	--	--
15R	6+47.00D	305.0	--	--	--	--	--	--	--	--	--	--	--

Table 8

Maximum Water Surface Downstream of Miter Gate and Over Left Culvert Outlet During Emptying and Maximum Differential Across Miter Gate After Emptying

84-Ft Lift (Upper Pool El 414, Lower Pool El 330)

Valve Time, V_t	Empty Time, E_t	During Emptying Maximum Rise in Water Surface and Occurrence Time: Downstream Miter Gate		Over Left Outlet		After Emptying: Maximum Undertravel in Chamber and Occurrence Time			Minimum or Maximum Water Surface: Downstream Miter Gate		Above Left Outlet		Differential Across Miter Gate
min	min	ft	min	ft	min	ft	el	min	ft	el	ft	el	ft
Normal, 2 Valves													
1	12.8	3.2	1.1	2.7	1.0	-1.0	329.0	14.25	-0.08	329.92	-0.05	329.95	0.92
2	13.3	2.1	1.8	1.7	1.8	-1.1	328.9	14.85	-0.05	329.95	+0.08	330.08	1.05
4	14.3	1.0	3.5	1.5	3.6	-1.1	328.9	15.9	-0.10	329.90	-0.12	329.88	1.0
Single, Left Valve													
1	24.1	1.2	1.1	1.2	1.1	-0.7	329.3	26.1	0.0	330.0	+0.6		0.7
2	24.6	1.1	1.9	0.7	1.7	-0.8	329.2	26.75	+0.4	330.4	+0.6		0.7

Note: Type 17 filling and emptying system. Occurrence time denotes time after beginning of valve movement.

Table 9

Type 17 (Recommended) Filling and Emptying System, Reservoir Evacuation Plan 1 (Left Filling Valve and Lower Miter Gates Open; Right Filling Valve, Left and Right Emptying Valves, and Upstream Miter Gates Closed)

Water-Surface Elevations, ft msl						
Outside Guide Wall	Vicinity Intake	Lock Chamber	Tailwater Canal	Flow Conditions at Left Wall Intake Manifold	Flow Conditions at Right Wall Intake Manifold	Average Negative Piezometer Reading in System Feet of Water
358.6	358.4	330.1	330.0	Calm with water surface below intake roof	The right intake is inactive	None
364.7	364.5	330.2		Slow circular flow through bulkhead R 7-8		
369.7	366.8	330.6		Air drawn into top intake		
378.9	378.4	330.9		Small vortex occasionally entrains air		
385.0	385.0	331.1		3-ft surface diameter occasionally entrains air, ports 7-10		
392.1	392.1	331.2		3-ft surface diameter occasionally entrains air, ports 7-10		
398.2	398.2	331.3		3-ft surface diameter occasionally entrains air, ports 7-10		
405.8	405.8	331.6		Slow circular flow with occasional swirls		Crossover Pier 2-TS -2.3 Pier 4-TS -2.0
410.6	410.6	331.7		Slow circular flow, very calm occasional swirl		Crossover Pier 2-TS -4.0 Pier 4-TS -4.1
418.4	418.4	331.9		Very little movement, no swirls		Crossover Pier 2-TS -6.7 Pier 4-TS -6.3

Table 10

Type 17 (Recommended) Filling and Emptying System, Reservoir Evacuation Plan 2

(Left and Right Filling Valves and Lower Miter Gate Open; Left and Right Emptying Valves and Upper Miter Gates Closed)

Water-Surface Elevations, ft msl						
Outside Guide Wall	Vicinity Intake	Upstream End Chamber	Tailwater Canal	Flow Conditions at Left Wall Intake Manifold	Flow Conditions at Right Wall Intake Manifold	Average Negative Piezometer Reading in System Feet of Water
357.3	356.7	330.0	330.0	Slow circular flow through bulkhead R 7-8	Slow circular flow through bulkhead R 7-8	None
363.7	362.5	330.3		Slow circular flow through bulkhead R 7-8	Slow circular flow through bulkhead R 7-8	
369.7	366.0	330.5		Slow circular flow through bulkhead R 7-8	Slow circular flow through bulkhead R 7-8	
374.5	368.2	331.5		Air drawn into top intake ports	Air drawn into top intake ports	
	374.8	332.2		Strong circular flow through bulkhead R 7-8, no swirls	Strong circular flow through bulkhead R 7-8, no swirls	
	377.5	332.9		No air drawn, swirls try to form near downstream ports	No air drawn, swirls try to form near downstream ports	
	380.9	333.2		Circular flow through bulkhead continues, swirls over downstream ports of intakes	Circular flow through bulkhead continues, swirls over downstream ports of intakes	
	382.5	333.4		Vortexes trying to form at downstream ports	Vortexes trying to form at downstream ports	
	388.1	333.6		Occasional vortexes with little air drawn	Occasional vortexes with little air drawn	
	392.1	334.0		Occasional vortexes with little air drawn	Occasional vortexes with little air drawn	

(Continued)

Table 10 (Concluded)

Water-Surface Elevations, ft msl: Outside Guide Wall	Vicinity Intake	Upstream End Chamber	Tailwater Canal	Flow Conditions at Left Wall Intake Manifold	Flow Conditions at Right Wall Intake Manifold	Average Negative Piezometer Reading in System Feet of Water
	397.0	334.4	330.0	Occasional vortexes with little air drawn	Occasional vortexes with little air drawn	None
	401.2	334.5		Air entraining vortexes over ports 2-4, swaps intake	Air entraining vortexes over ports 2-4, swaps intakes	
	405.5	334.9		Vortex over ports 3-5, occasionally entrains air	Vortex over ports 3-5, occasionally entrains air	
	409.0	335.0		Occasional air entraining vortexes at any ports along manifold	Occasional air entraining vortexes at any ports along manifold	
	412.6	335.3		10-ft surface diameter air entraining vortex at upstream end of intake	Intermittent 5-ft surface diameter air entraining vortex over middle ports	
	416.0	335.5		10-ft surface diameter air entraining vortex at upstream end of intake	2- to 3-ft surface diameter over middle ports	
	421.6	335.9		5-ft surface diameter air entraining vortex over middle ports	Intermittent 5-ft surface diameter vortex over middle ports	
	425.8	336.1		12-ft surface diameter air entraining vortex	Occasional 5-ft surface diameter vortex along right intake manifold	
	429.3	336.4		12-ft surface diameter air entraining vortex	None	

Table 11

Type 17 (Recommended) Filling and Emptying System Reservoir Evacuation Plan 3

(Left Filling Valve and Right Emptying Valve Open; Miter Gates, Right Filling and Left Emptying Valves Closed)

Water-Surface Elevations, ft msl						
Outside Guide Wall	Vicinity Intake	Lock Chamber	Tailwater Canal	Flow Conditions at Left Wall Intake Manifold	Flow Conditions at Right Wall Intake Manifold	Average Negative Piezometer Reading in System Feet of Water
356.6	356.4	330.1	330.0	Slow circular flow through bulkhead R 7-8	The right intake is inactive	None
361.4	361.2	330.8		Slow circular flow through bulkhead R 7-8		
367.3	366.6	340.4		Slow circular flow, occasional small swirl, air being drawn into top intake ports		
373.0	372.0	358.4		Slow circular flow, occasional small swirl, no air being drawn into to intake		
379.2	379.2	363.0		Slow circular flow, small swirls and small vortex along intake wall		
385.5	385.5	367.4		Small vortexes form occasionally over ports 8-10		
393.0	393.0	372.5		Occasional small vortex		
398.5	398.5	376.1		Slow circular movement very calm		
405.1	405.1	380.5		Very calm		
413.2	413.2	385.7		Very calm		
418.1	418.1	389.0		Very calm		

a. 1.5 min after filling started

b. 4.0 min after filling started

Photo 1. Surface currents during filling operation at type 1 (original intakes) with original guide and guard walls installed. Upper pool el 4.4 and initial lower pool el 330, 1-min valve time. Top of intake ports submerged 48 ft, time exposure 5 sec (Sheet 1 of 2)

c. 6.5 min after filling started

d. 9.0 min after filling started

Photo 1 (Sheet 2 of 2)

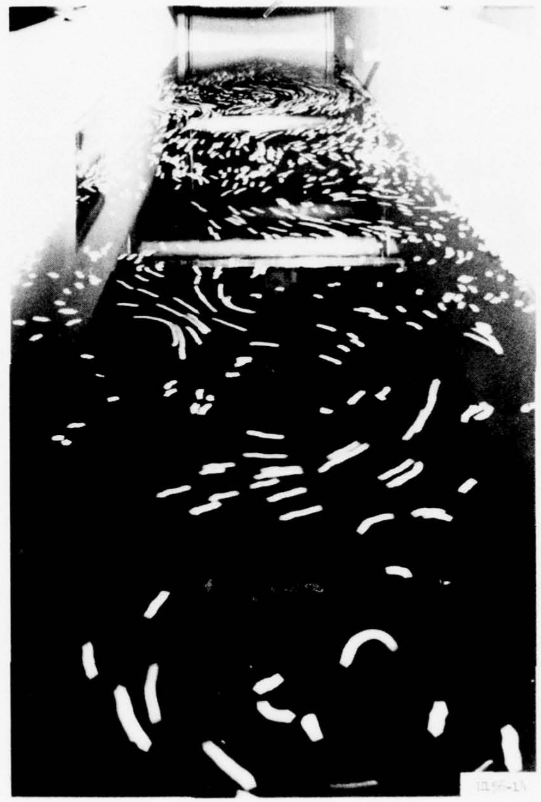
a. Before filling started

b. 1 min after filling started

c. 2 min after filling started

Photo 2. Surface currents in lock chamber during filling operation with type 1 culvert arrangement, 1-min valve time (Sheet 1 of 2)

d. 4 min after filling started



e. 6 min after filling started

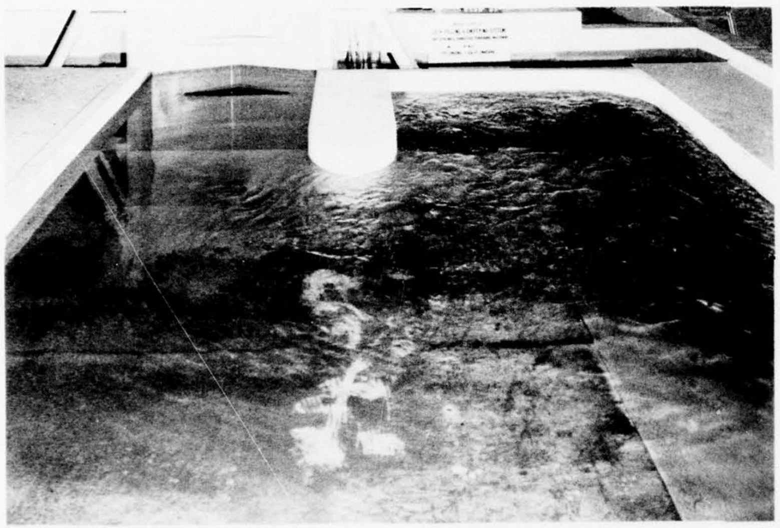
f. 8 min after filling started

Photo 2 (Sheet 2 of 2)

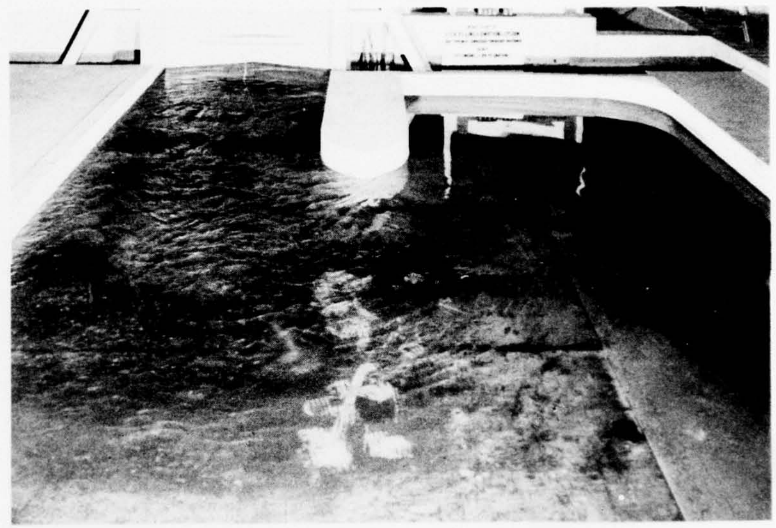
a. Normal 1-min valve emptying operation

b. Normal 2-min valve emptying operation

Photo 3. Maximum discharge and flow conditions, type 2 outlets, guard wall, and approach channel; initial head 84 ft (lock chamber) el 414, lower pool el 330 (Sheet 1 of 2)



c. Single 2-min left valve emptying operation



d. Single 2-min right valve emptying operation

Photo 3 (Sheet 2 of 2)

a. Before filling started   b. 1 min after filling started   c. 2 min after filling started

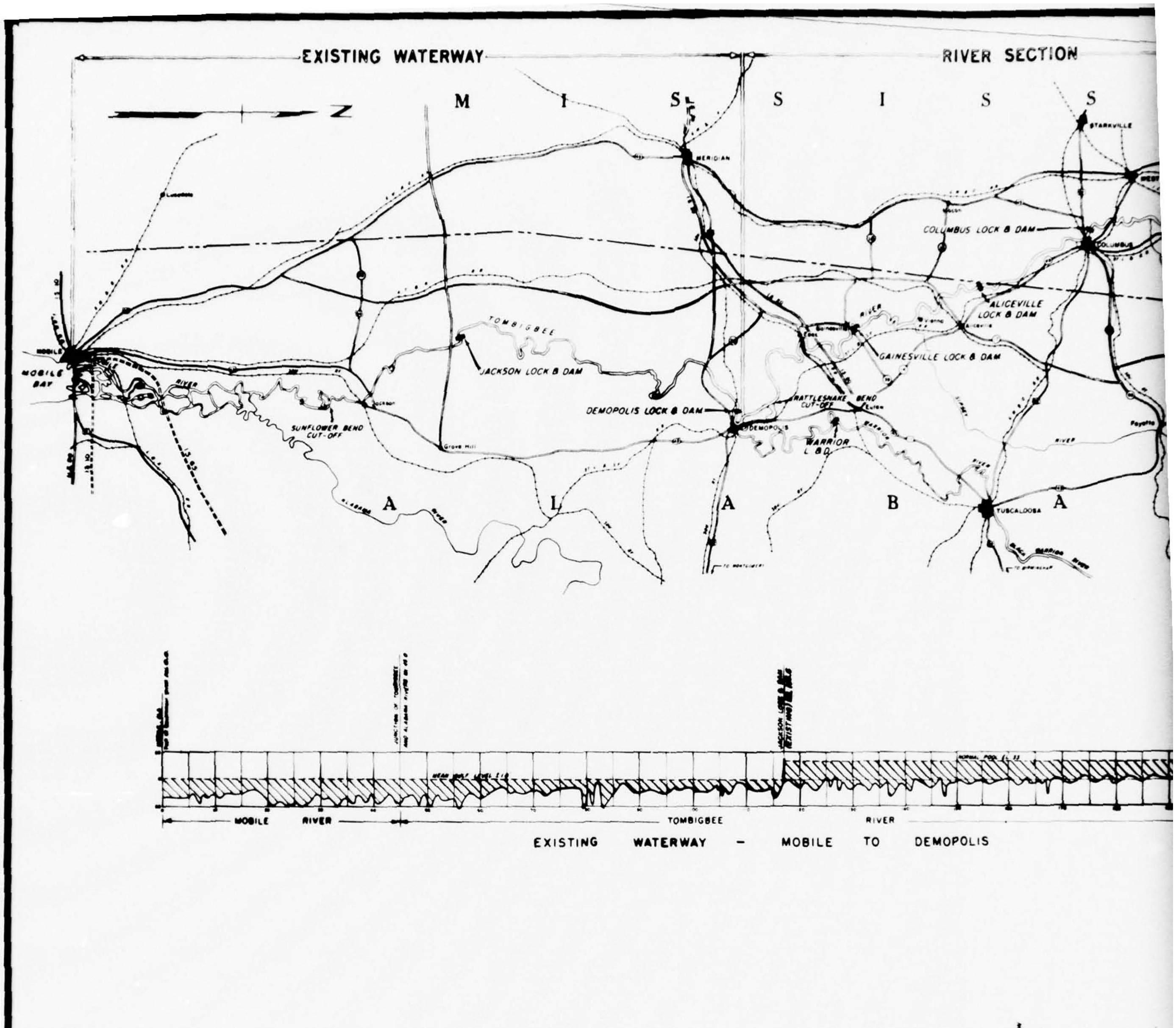
Photo 4. Surface currents in lock chamber during filling operation with type 17 (recommended) culvert arrangement, 1-min valve time (Sheet 1 of 2)

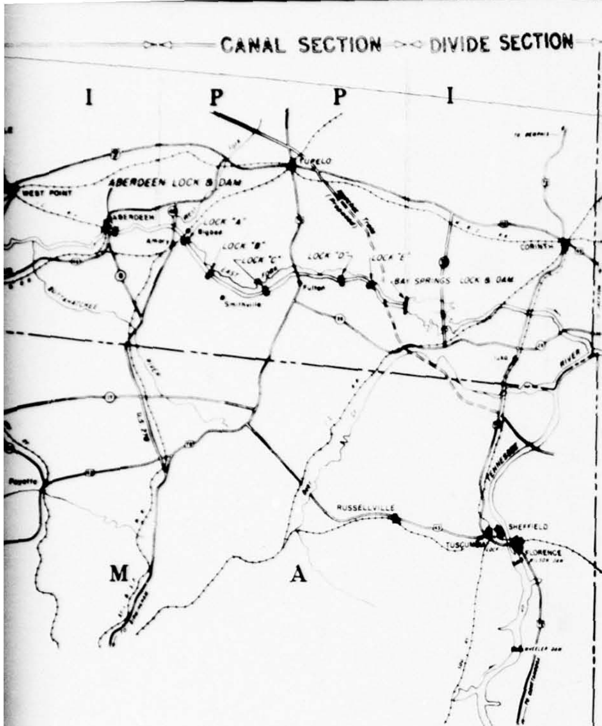
d. 4 min after filling started

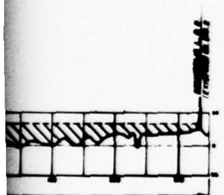
e. 6 min after filling started

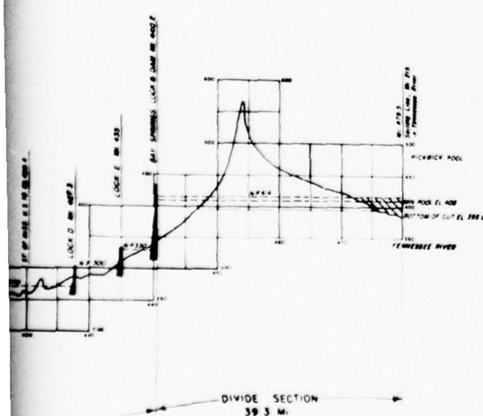
f. 8 min after filling started

Photo 4 (Sheet 2 of 2)


EXISTING WATERWAY
RIVER SECTION
M I S S I S S
A L A B A
MERIDIAN
STARKVILLE
COLUMBUS LOCK & DAM
COLUMBUS
ALICEVILLE LOCK & DAM
GAINESVILLE LOCK & DAM
TOMBIGBEE
JACKSON LOCK & DAM
DEMOPOLIS LOCK & DAM
DEMOPOLIS
RATTLESNAKE BEND CUT-OFF
WARRIOR L.&D.
TUSCALOOSA
SUNFLOWER BEND CUT-OFF
MOBILE
MOBILE BAY
RIVER
Grove Hill
MOBILE RIVER
TOMBIGBEE RIVER
EXISTING WATERWAY - MOBILE TO DEMOPOLIS
RIVER SECTION
CANAL SECTION
45.6 MI
33.03 MI
11.0 MI
46.83 MI
30.65 MI
RIVER MILES ABOVE MOUTH
TENNESSEE - TOMBIGBEE WATERWAY







LEGEND

LOCK AND DAM, EXISTING OR UNDER CONSTRUCTION

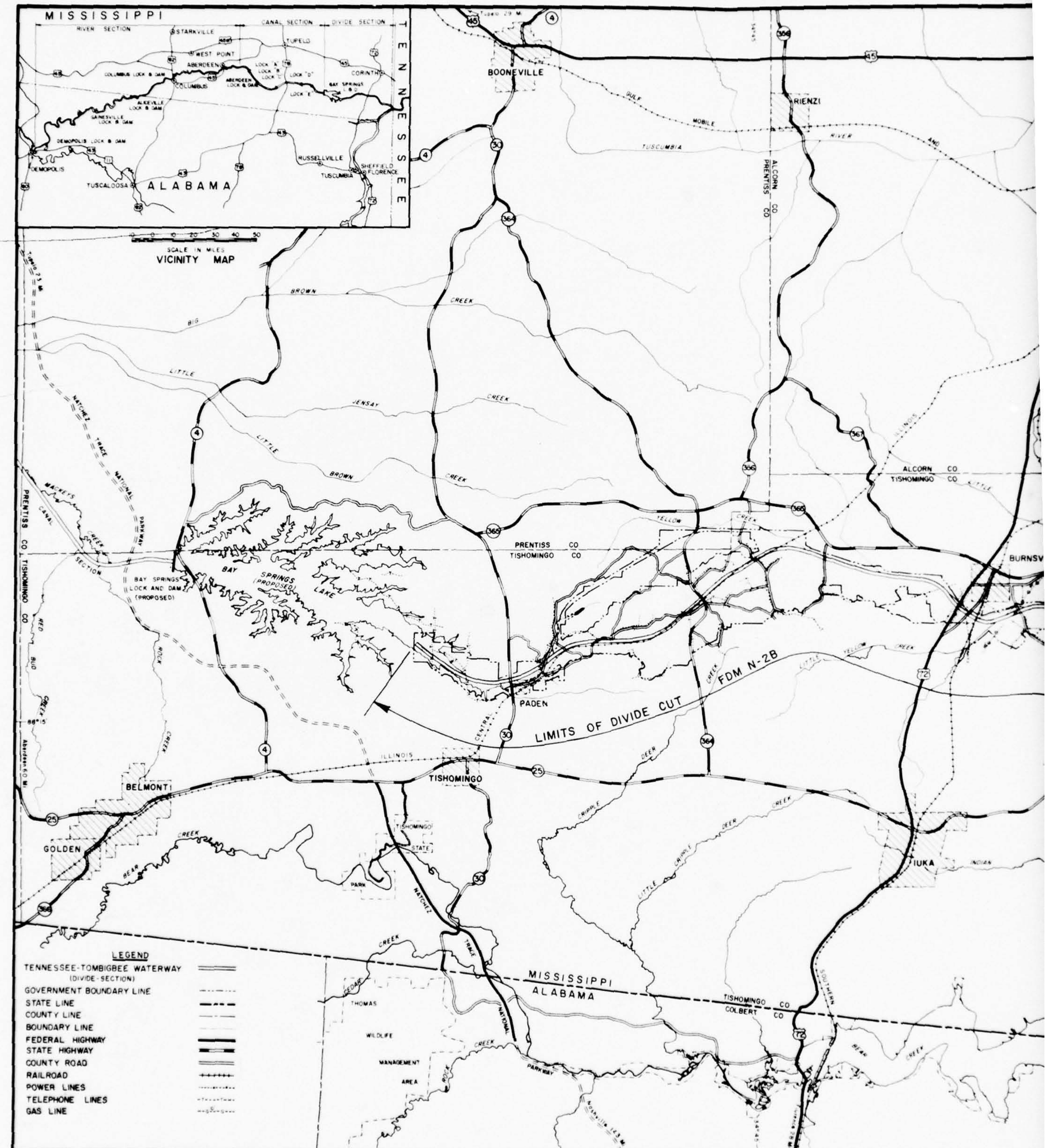
PROPOSED LOCK AND DAM

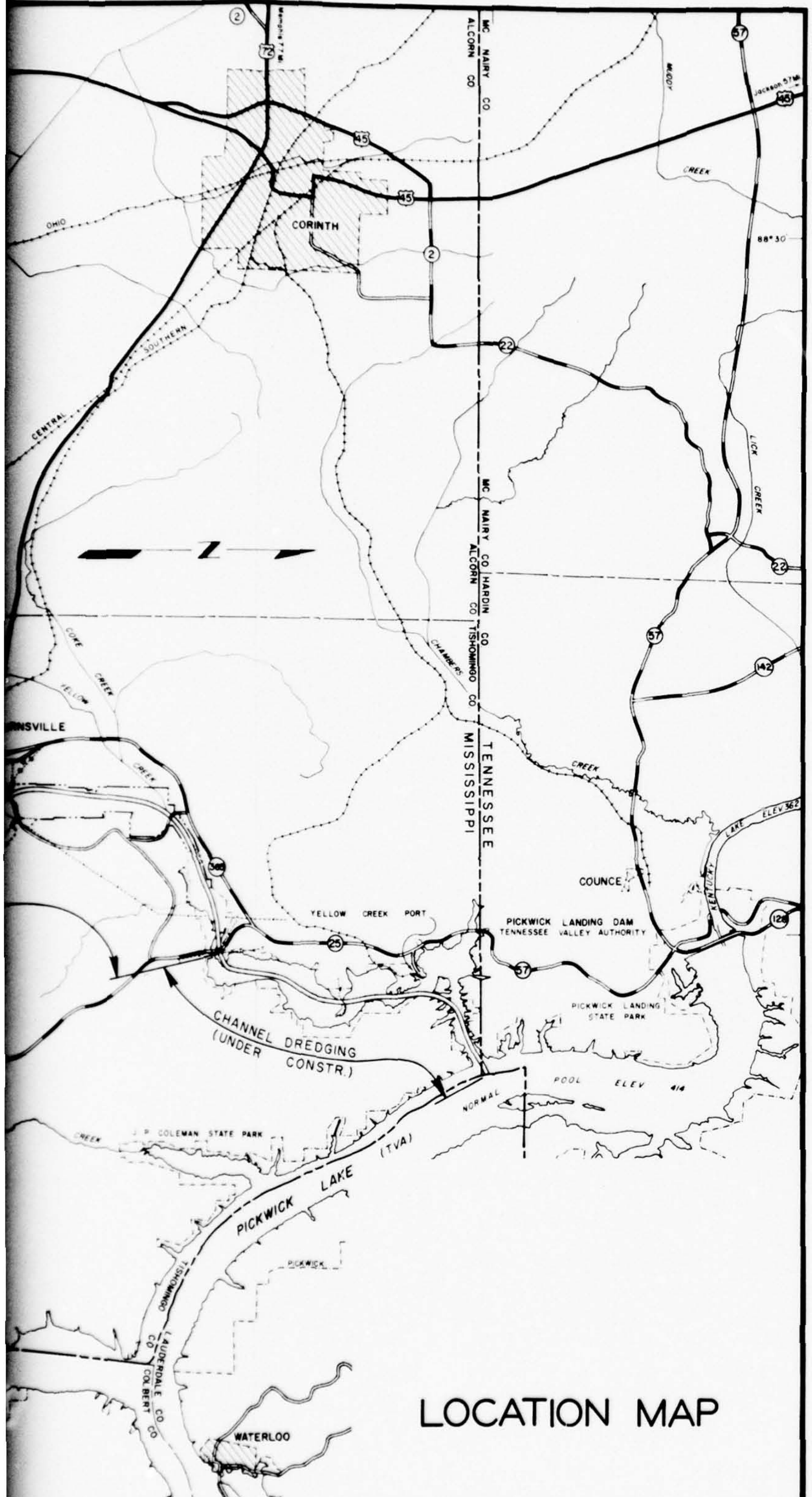
NOTE: Mileages shown are measured along authorized navigation channel and vary somewhat from those shown in previous documents. Mileages in Canal and Divide Sections are subject to correction by subtraction of 9.36 miles.

GENERAL PLAN AND PROFILE

SCALE IN MILES

10 5 0 10 20 30

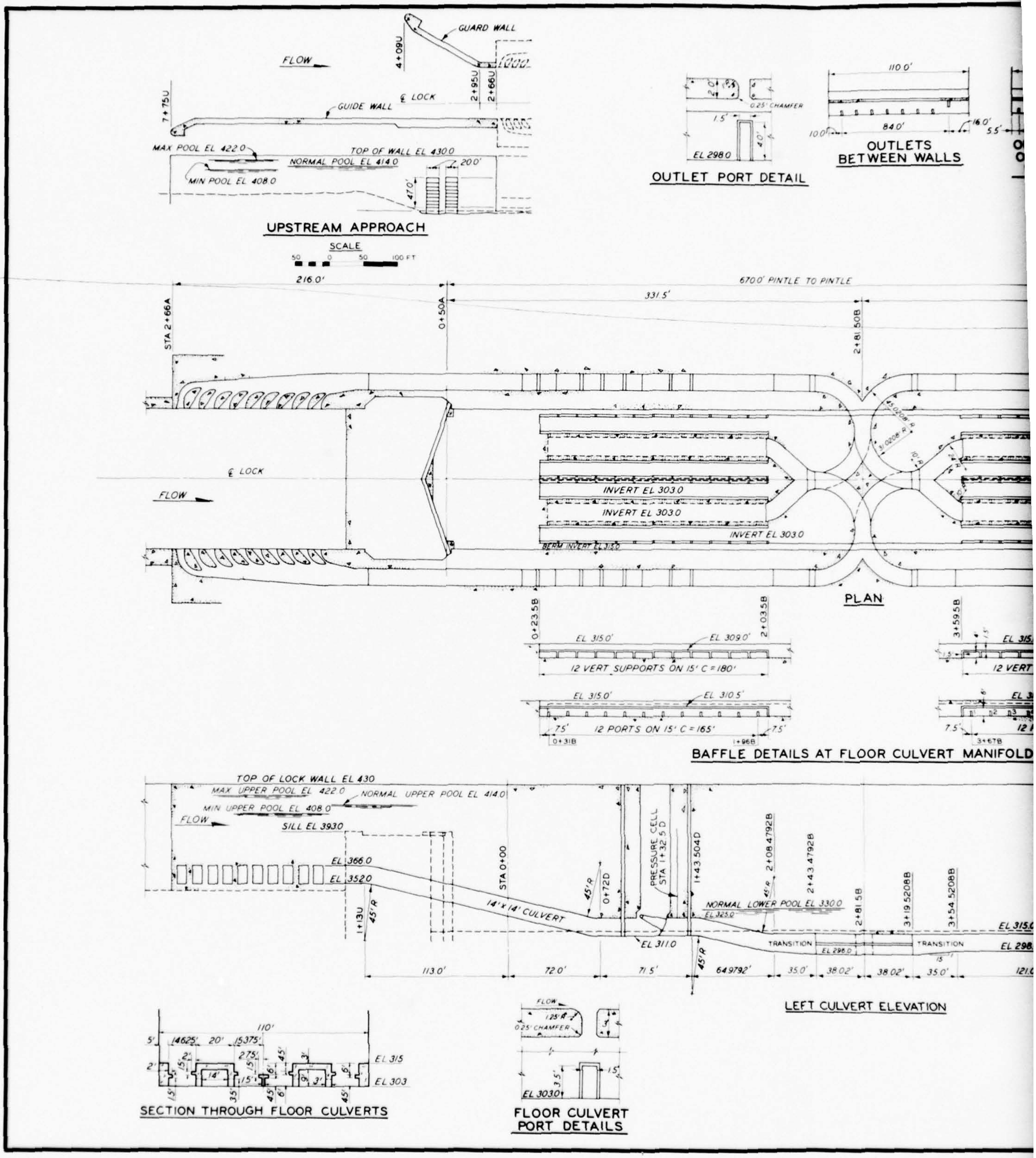

MISSISSIPPI
RIVER SECTION
CANAL SECTION
DIVIDE SECTION
STARKVILLE
TUPELO
WEST POINT
ABERDEEN
COLUMBUS LOCK & DAM
COLUMBUS
ABERDEEN LOCK & DAM
CORINTH
BAY SPRINGS L & D
ALICEVILLE LOCK & DAM
GAINESVILLE LOCK & DAM
DEMOPOLIS LOCK & DAM
DEMOPOLIS
RUSSELLVILLE
SHEFFIELD
FLORENCE
TUSCUMBIA
TUSCALOOSA
ALABAMA
TENNESSEE
SCALE IN MILES
VICINITY MAP
BOONEVILLE
RIENZI
GULF
MOBILE
RIVER
TUSCUMBIA
ALCORN CO
PRENTISS CO
BIG
BROWN
CREEK
LITTLE
JENSAY
CREEK
LITTLE
BROWN
CREEK
NATCHEZ TRACE NATIONAL PARKWAY
MACKEYS CREEK
CANAL SECTION
PRENTISS CO
TISHOMINGO CO
ALCORN CO
TISHOMINGO CO
YELLOW CREEK
PRENTISS CO
TISHOMINGO CO
BAY SPRINGS LOCK AND DAM (PROPOSED)
BAY SPRINGS (PROPOSED) LAKE
BURNSV
RED BUD CREEK
PADEN
LIMITS OF DIVIDE CUT
FDM N-2B
LITTLE YELLOW CREEK
ILLINOIS
CENTRAL
BELMONT
TISHOMINGO
GOLDEN
BEAR CREEK
TISHOMINGO STATE PARK
CRIPPLE DEER CREEK
LITTLE CRIPPLE DEER
IUKA
INDIAN
MISSISSIPPI
ALABAMA
TISHOMINGO CO
COLBERT CO
THOMAS WILDLIFE MANAGEMENT AREA
CEDAR CREEK
ROCK CREEK
NATCHEZ TRACE NATIONAL PARKWAY
SOUTHERN
BEAR CREEK
LEGEND
TENNESSEE-TOMBIGBEE WATERWAY (DIVIDE-SECTION)
GOVERNMENT BOUNDARY LINE
STATE LINE
COUNTY LINE
BOUNDARY LINE
FEDERAL HIGHWAY
STATE HIGHWAY
COUNTY ROAD
RAILROAD
POWER LINES
TELEPHONE LINES
GAS LINE

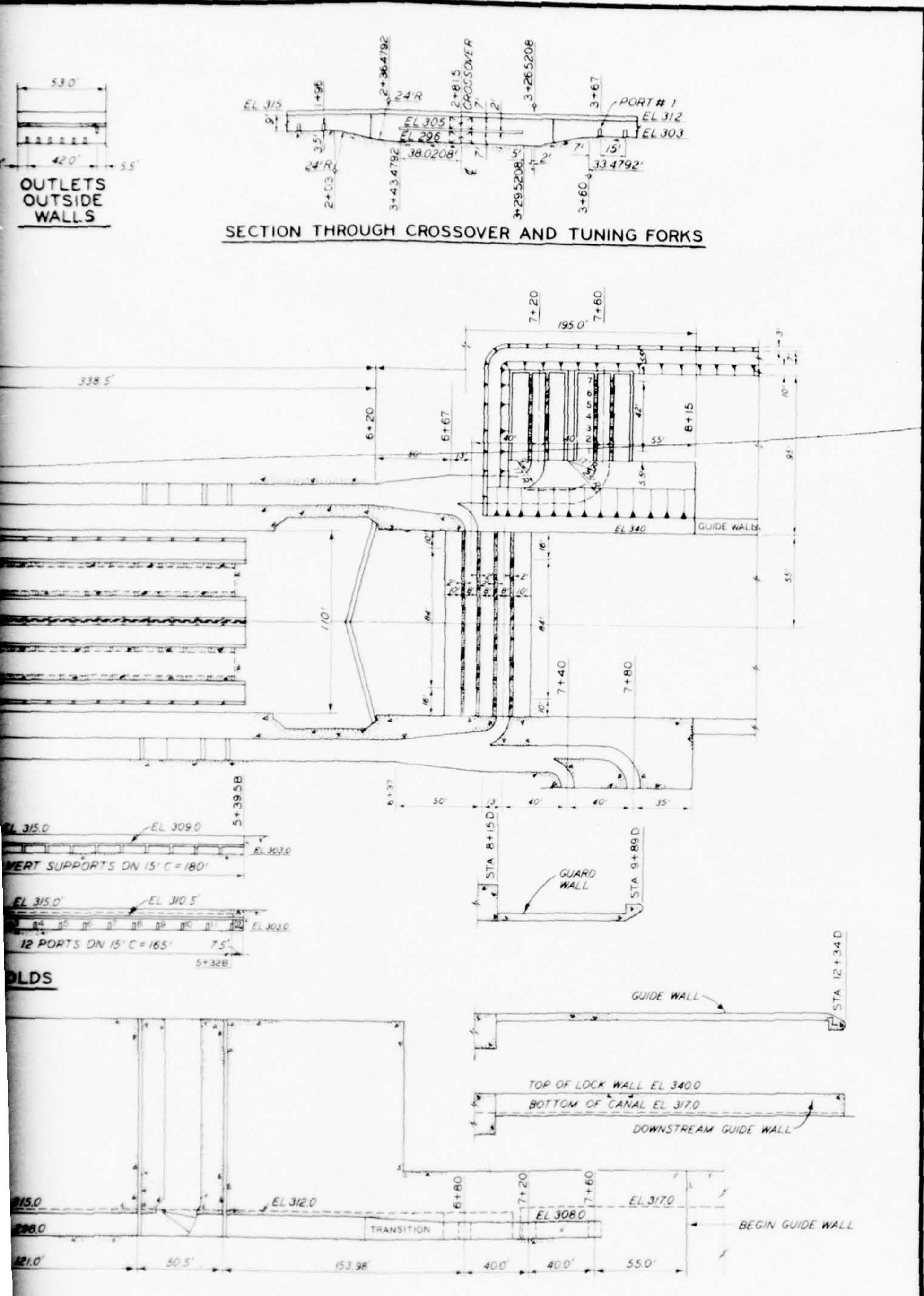


CORINTH
COUNCE
YELLOW CREEK PORT
PICKWICK LANDING DAM
TENNESSEE VALLEY AUTHORITY
PICKWICK LANDING STATE PARK
CHANNEL DREDGING
(UNDER CONSTR.)
J. P. COLEMAN STATE PARK
PICKWICK LAKE (TVA)
NORMAL POOL ELEV 414
TENNESSEE
MISSISSIPPI
MC NAIRY CO
ALCORN CO
HARDIN CO
TISHOMINGO CO
LAUDERDALE CO
COLBERT CO
WATERLOO
LOCATION MAP

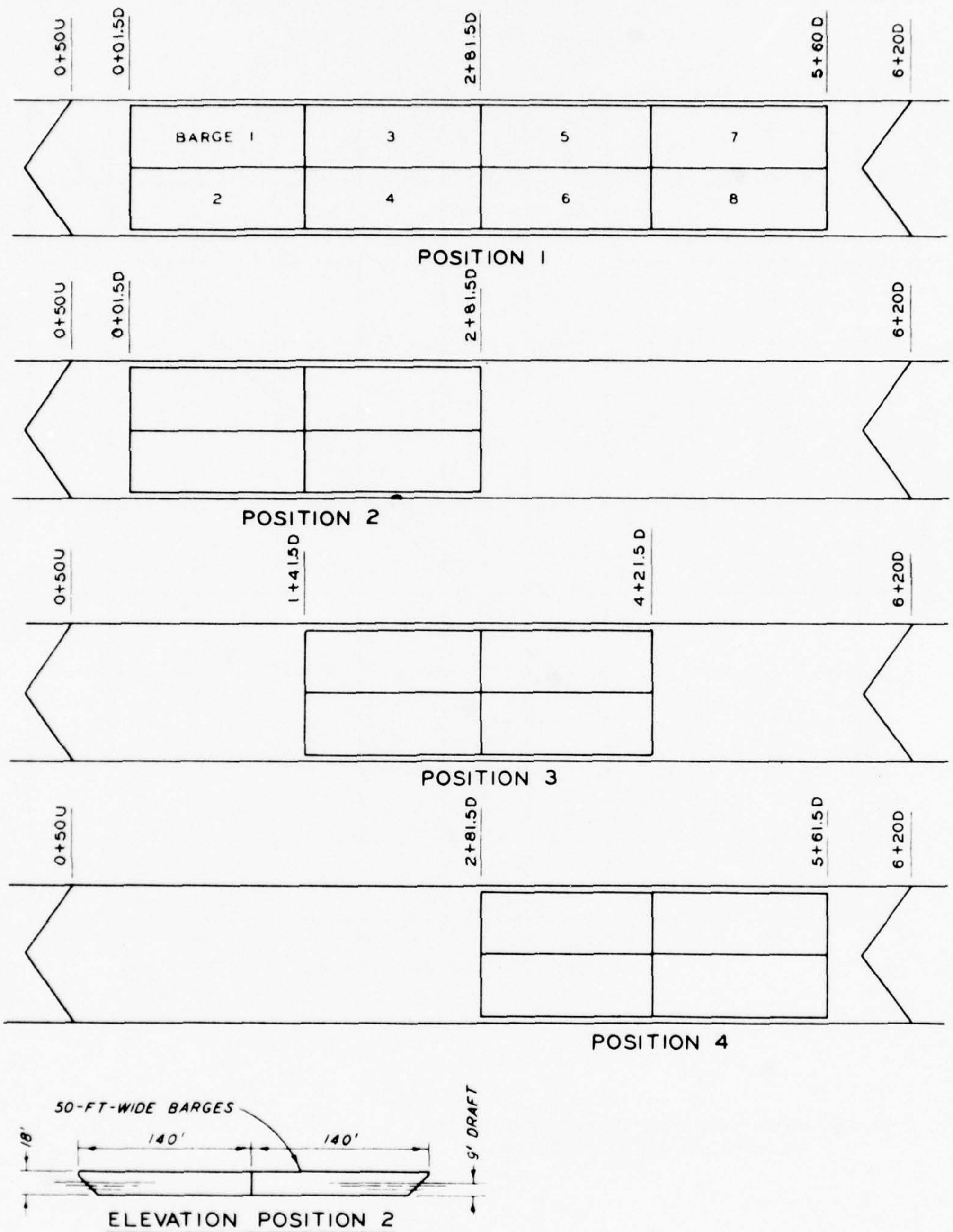
PLATE 2

2


FLOW
GUARD WALL
GUIDE WALL
℄ LOCK
MAX POOL EL 422.0
TOP OF WALL EL 430.0
NORMAL POOL EL 414.0
MIN POOL EL 408.0
UPSTREAM APPROACH
SCALE
50 0 50 100 FT
OUTLET PORT DETAIL
0.25' CHAMFER
EL 298.0
OUTLETS BETWEEN WALLS
110.0'
84.0'
216.0'
670.0' PINTLE TO PINTLE
331.5'
STA 2+66A
0+50A
2+81.50B
INVERT EL 303.0
BERM INVERT EL 315.0
PLAN
EL 315.0'
EL 309.0'
12 VERT SUPPORTS ON 15' C = 180'
EL 310.5'
12 PORTS ON 15' C = 165'
BAFFLE DETAILS AT FLOOR CULVERT MANIFOLD
TOP OF LOCK WALL EL 430
MAX UPPER POOL EL 422.0
NORMAL UPPER POOL EL 414.0
MIN UPPER POOL EL 408.0
SILL EL 393.0
EL 366.0
EL 352.0
14' x 14' CULVERT
PRESSURE CELL STA 1+32.5 D
NORMAL LOWER POOL EL 330.0
EL 311.0
TRANSITION
LEFT CULVERT ELEVATION
SECTION THROUGH FLOOR CULVERTS
EL 315
EL 303
FLOOR CULVERT PORT DETAILS
EL 303.0

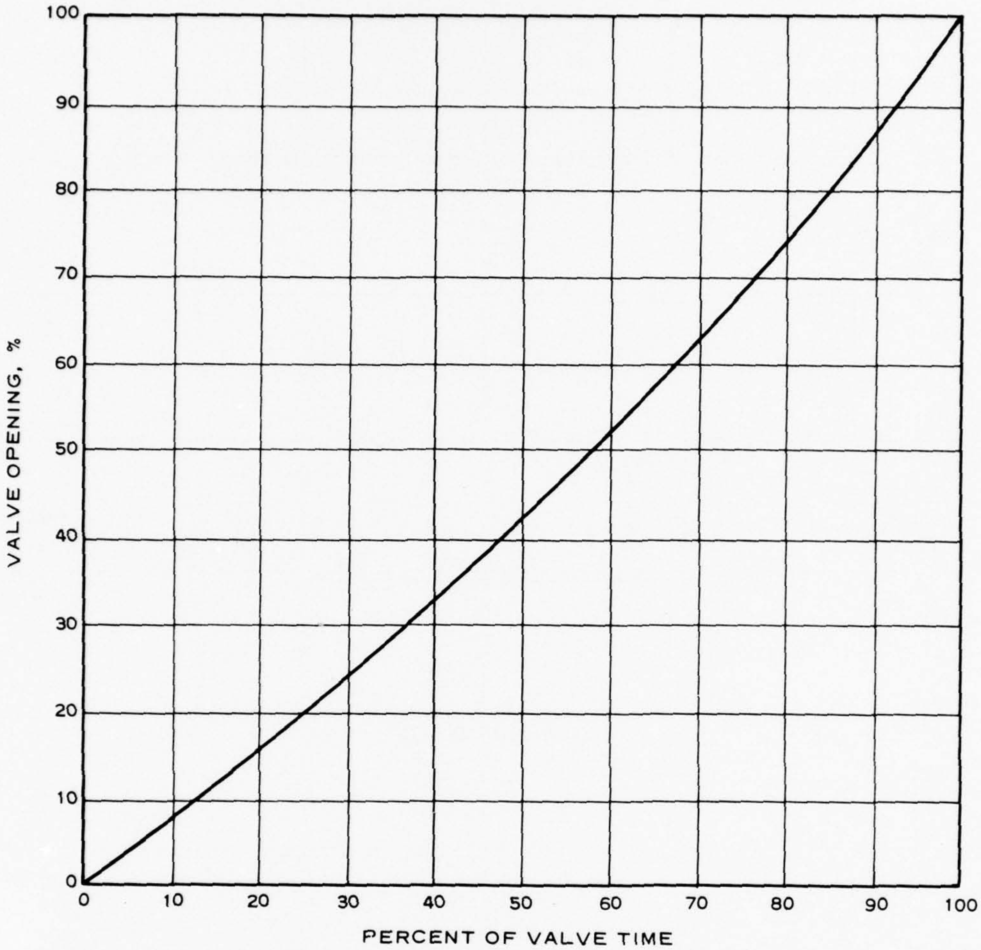


FILLING AND EMPTYING SYSTEM
TYPE I
ORIGINAL DESIGN



NOTE: STATION 2+81.5 IS CENTER LINE OF CENTRAL DISTRIBUTION SYSTEM.
BARGE DISPLACEMENT AT 9-FT DRAFT: 15,105 TONS FOR 8-BARGE TOW AND 7,240 TONS FOR 4-BARGE TOW.

BARGE POSITIONS AND DETAILS



NOTE: FURNISHED BY MOBILE DISTRICT, DRAWING DATED 25 FEB 1970.

CULVERT VALVE
OPENING SCHEDULE

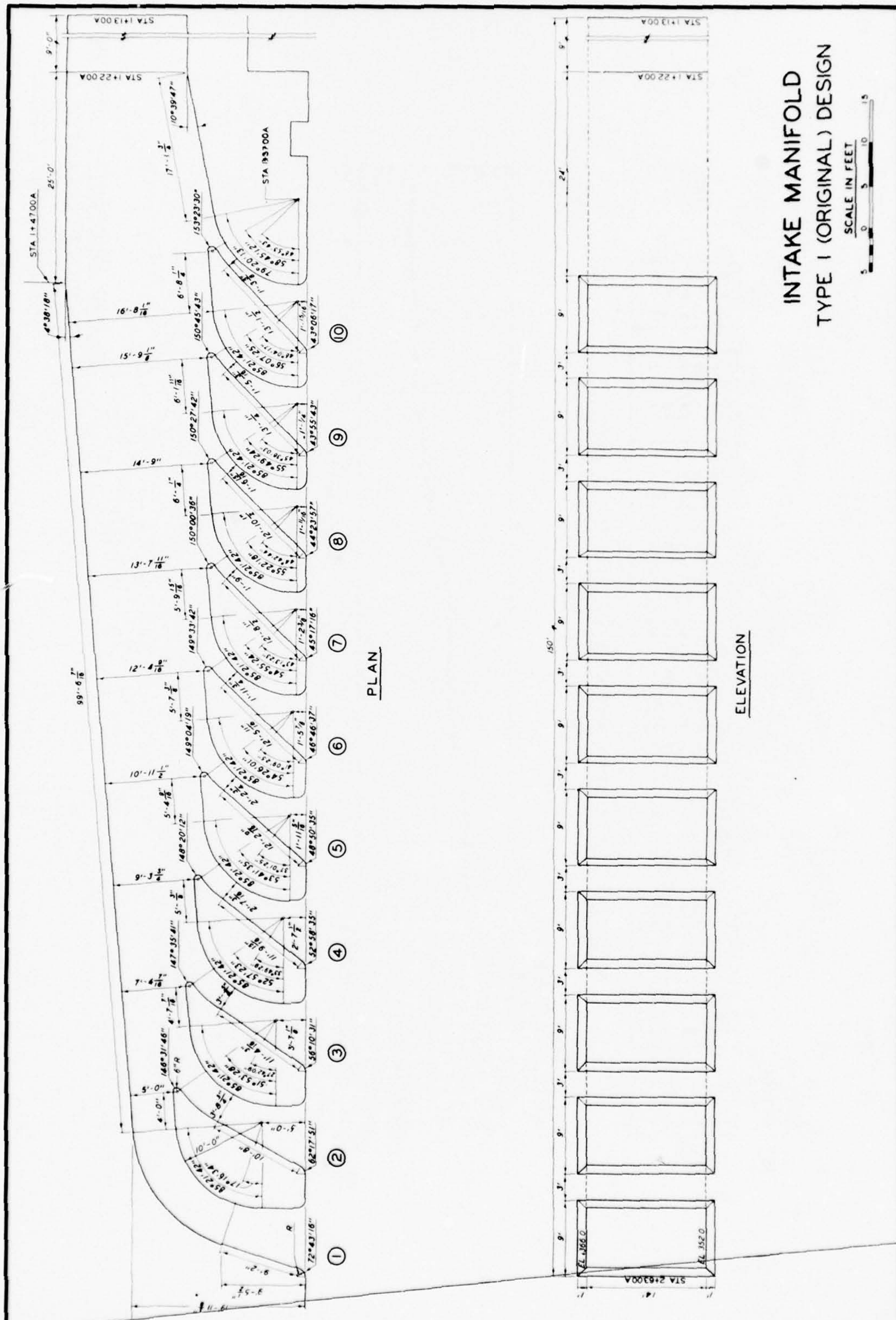
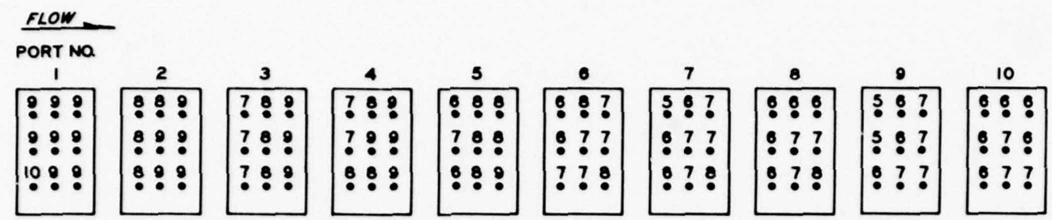
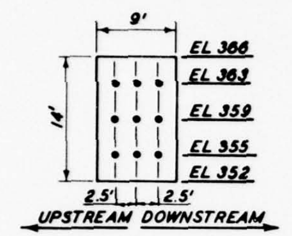

INTAKE MANIFOLD
TYPE 1 (ORIGINAL) DESIGN
SCALE IN FEET
PLAN
ELEVATION

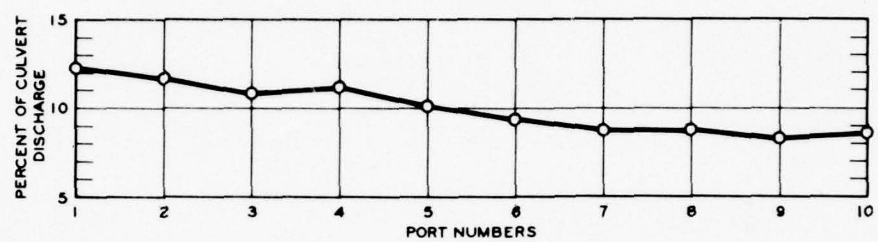
PLATE 6



VELOCITY DISTRIBUTION AT RIGHT WALL INTAKE PORTS



LOCATION OF PORT VELOCITY MEASUREMENTS



FLOW DISTRIBUTION

TEST CONDITIONS

DISCHARGE 9125 CFS PER CULVERT (FILLING VALVES OPEN FULL, EMPTYING VALVES CLOSED) LOWER MITER GATES OPEN.

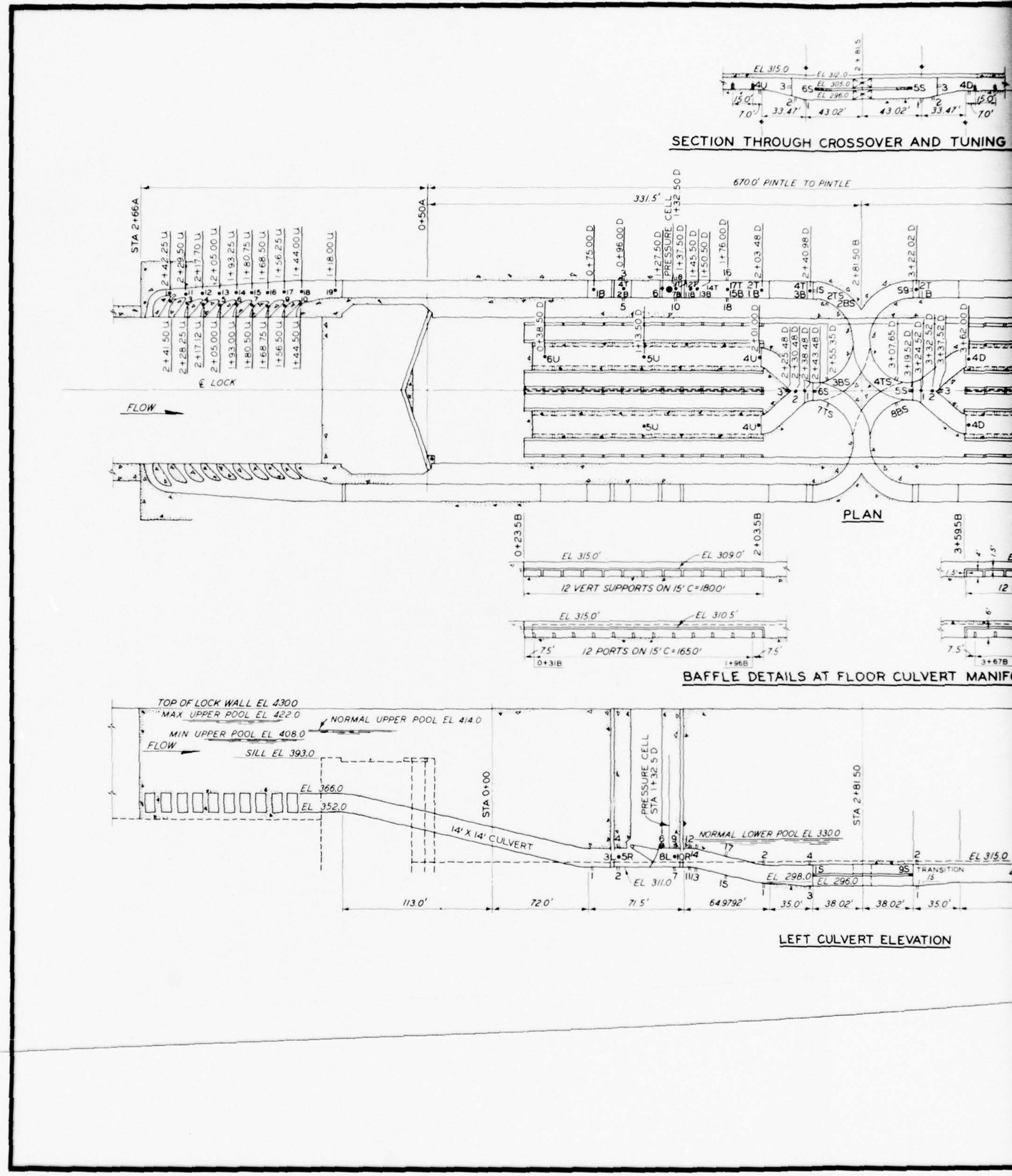
UPPER POOL EL 414.0

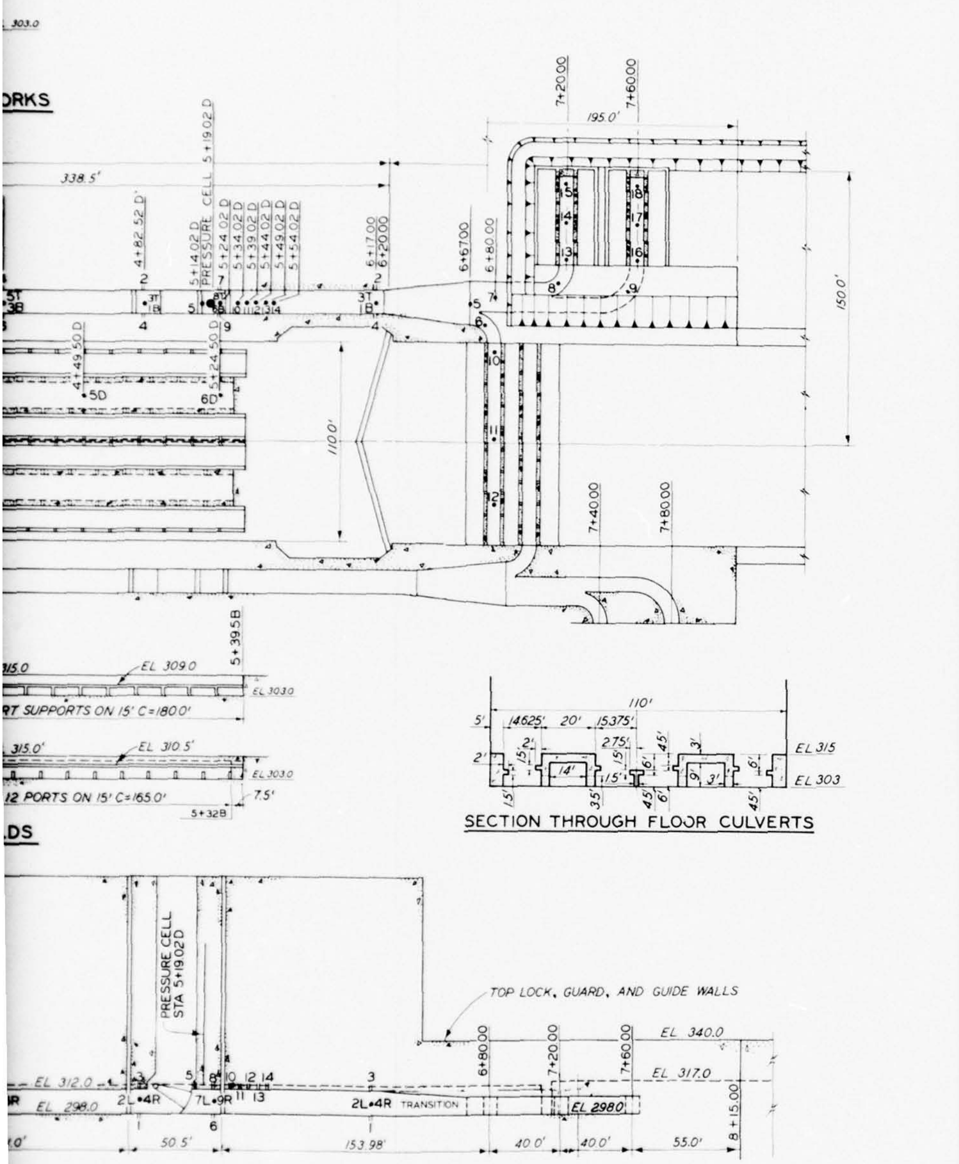
LOCK CHAMBER EL 341.0

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND AND ARE MEASURED AT WALL FACE OF INTAKE MANIFOLD.

FLOW DISTRIBUTION IN INTAKE MANIFOLD

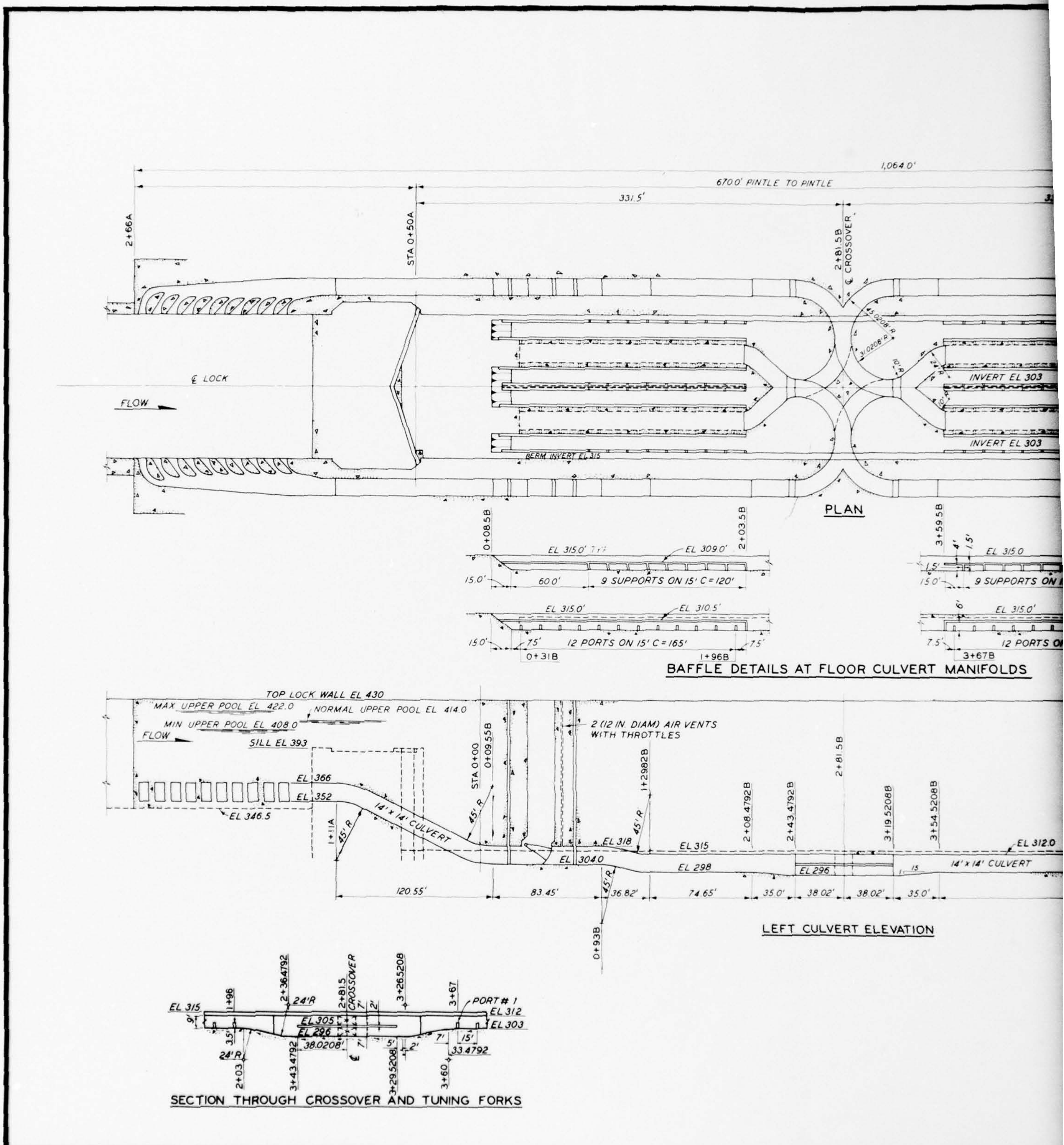
TYPE 1 (ORIGINAL) DESIGN

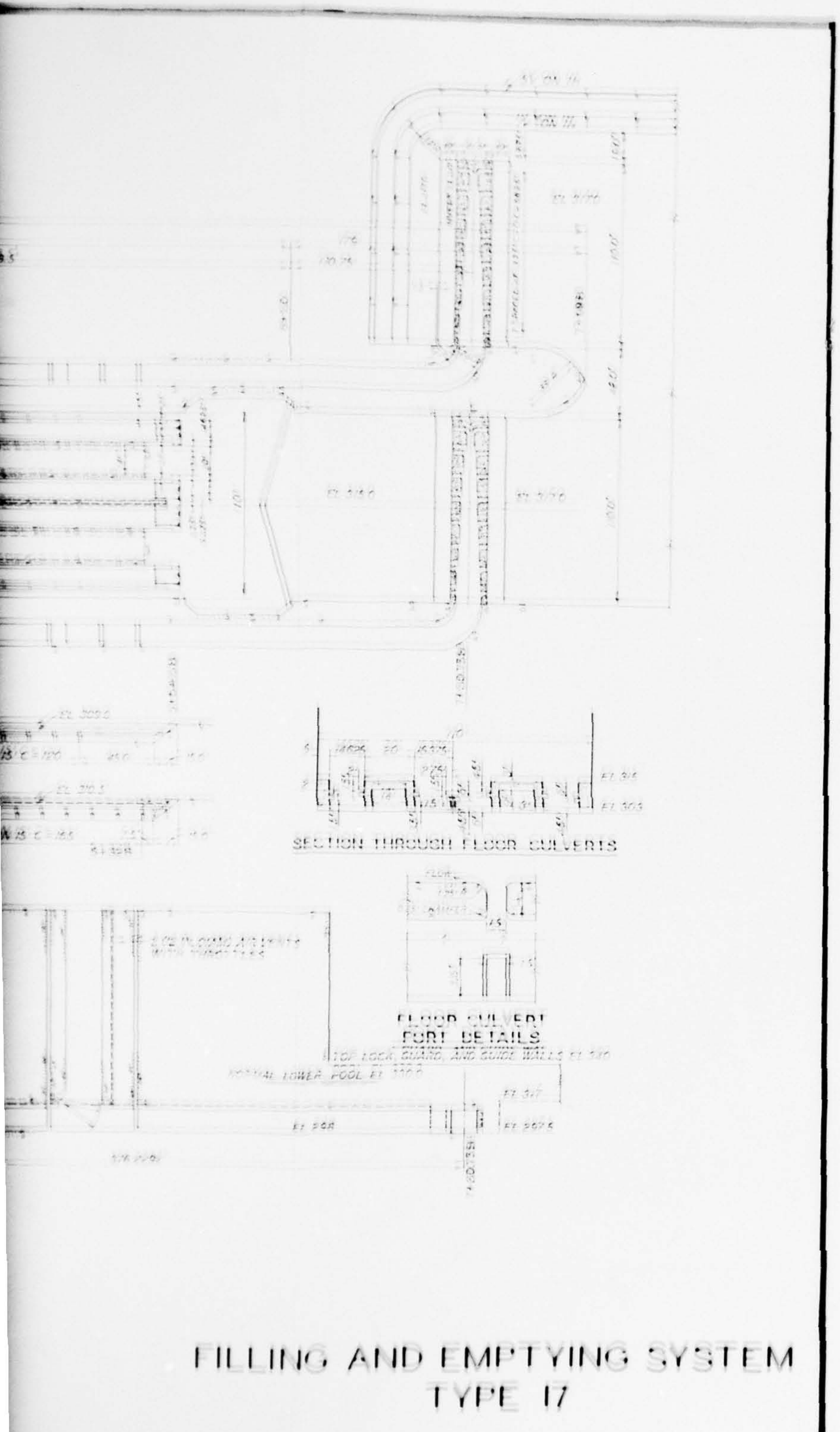

SECTION THROUGH CROSSOVER AND TUNING
EL 315.0
EL 312.0
EL 305.0
EL 296.0
33.47'
43.02'
7.0'
670.0' PINTLE TO PINTLE
331.5'
STA 2+66A
0+50A
PRESSURE CELL 1+32.50 D
€ LOCK
FLOW
PLAN
EL 315.0'
EL 309.0'
12 VERT SUPPORTS ON 15' C=180.0'
EL 310.5'
12 PORTS ON 15' C=165.0'
BAFFLE DETAILS AT FLOOR CULVERT MANIFOLD
TOP OF LOCK WALL EL 430.0
MAX UPPER POOL EL 422.0
NORMAL UPPER POOL EL 414.0
MIN UPPER POOL EL 408.0
SILL EL 393.0
EL 366.0
EL 352.0
STA 0+00
PRESSURE CELL STA 1+32.5 D
STA 2+81.50
14' X 14' CULVERT
NORMAL LOWER POOL EL 330.0
EL 311.0
EL 298.0
EL 296.0
EL 315.0
TRANSITION
113.0'
72.0'
71.5'
64.9792'
35.0'
38.02'
LEFT CULVERT ELEVATION



PIEZOMETER LOCATIONS FILLING AND EMPTYING SYSTEM TYPE I

ORIGINAL DESIGN

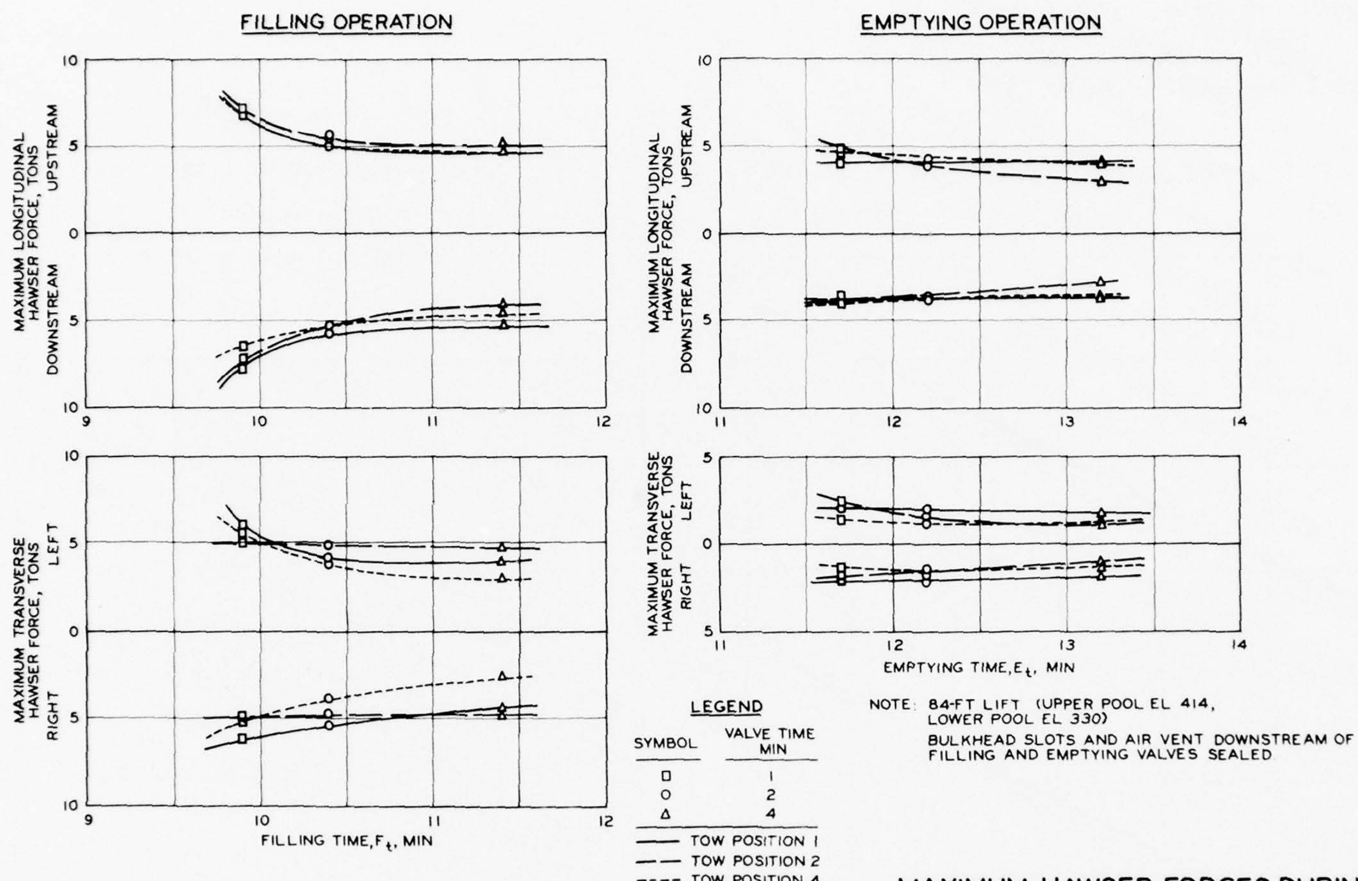

1,064.0'
670.0' PINTLE TO PINTLE
331.5'
2+66A
STA 0+50A
2+81.5B
℄ CROSSOVER
℄ LOCK
FLOW
INVERT EL 303
INVERT EL 303
BERM INVERT EL 315
PLAN
0+08.5B
2+03.5B
EL 315.0' TYP
EL 309.0'
15.0'
60.0'
9 SUPPORTS ON 15' C = 120'
EL 315.0'
EL 310.5'
7.5'
12 PORTS ON 15' C = 165'
0+31B
1+96B
3+59.5B
EL 315.0
9 SUPPORTS ON
3+67B
12 PORTS ON
BAFFLE DETAILS AT FLOOR CULVERT MANIFOLDS
TOP LOCK WALL EL 430
MAX UPPER POOL EL 422.0
NORMAL UPPER POOL EL 414.0
MIN UPPER POOL EL 408.0
FLOW
SILL EL 393
EL 366
EL 352
EL 346.5
14' x 14' CULVERT
1+11A
45' R
STA 0+00
0+09.55B
2 (12 IN. DIAM) AIR VENTS
WITH THROTTLES
1+29.82B
2+81.5B
2+08.4792B
2+43.4792B
3+19.5208B
3+54.5208B
EL 318
EL 315
EL 304.0
EL 298
EL 296
EL 312.0
14' x 14' CULVERT
120.55'
83.45'
36.82'
74.65'
35.0'
38.02'
38.02'
35.0'
0+93B
LEFT CULVERT ELEVATION
EL 315
1+96
2+36.4792
24' R
2+81.5
CROSSOVER
3+26.5208
3+67
PORT # 1
EL 312
EL 303
EL 305
EL 296
38.0208'
33.4792
24' R
2+03
3+43.4792
3+29.5208
3+60
SECTION THROUGH CROSSOVER AND TUNING FORKS



FILLING AND EMPTYING SYSTEM
TYPE 17

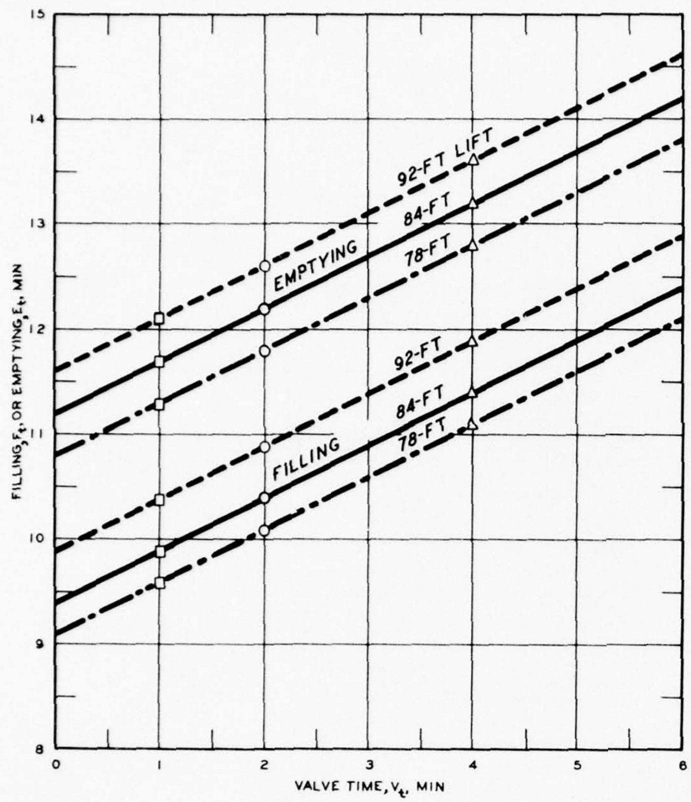
RECOMMENDED DESIGN

PLATE 9

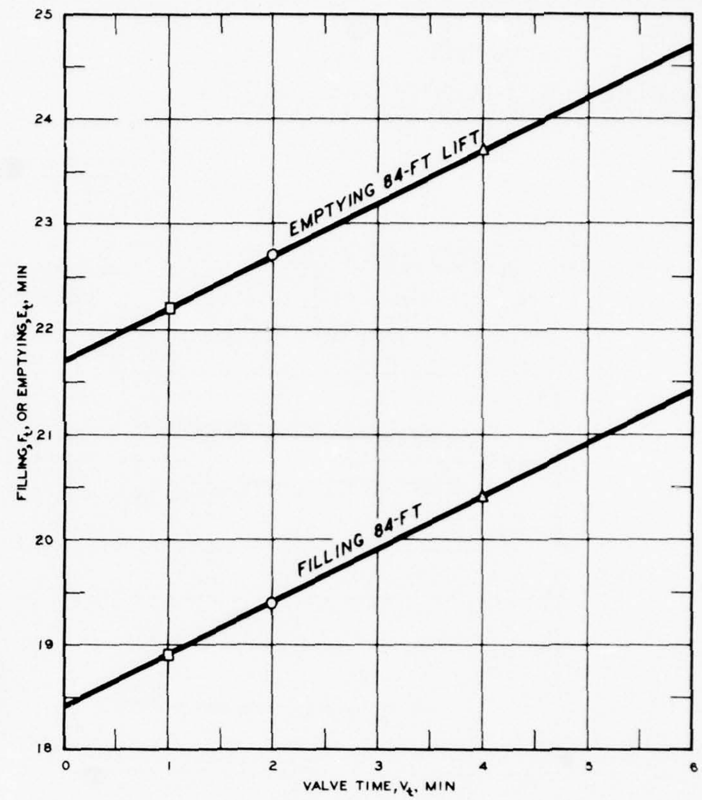


MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

TYPE I (ORIGINAL) DESIGN



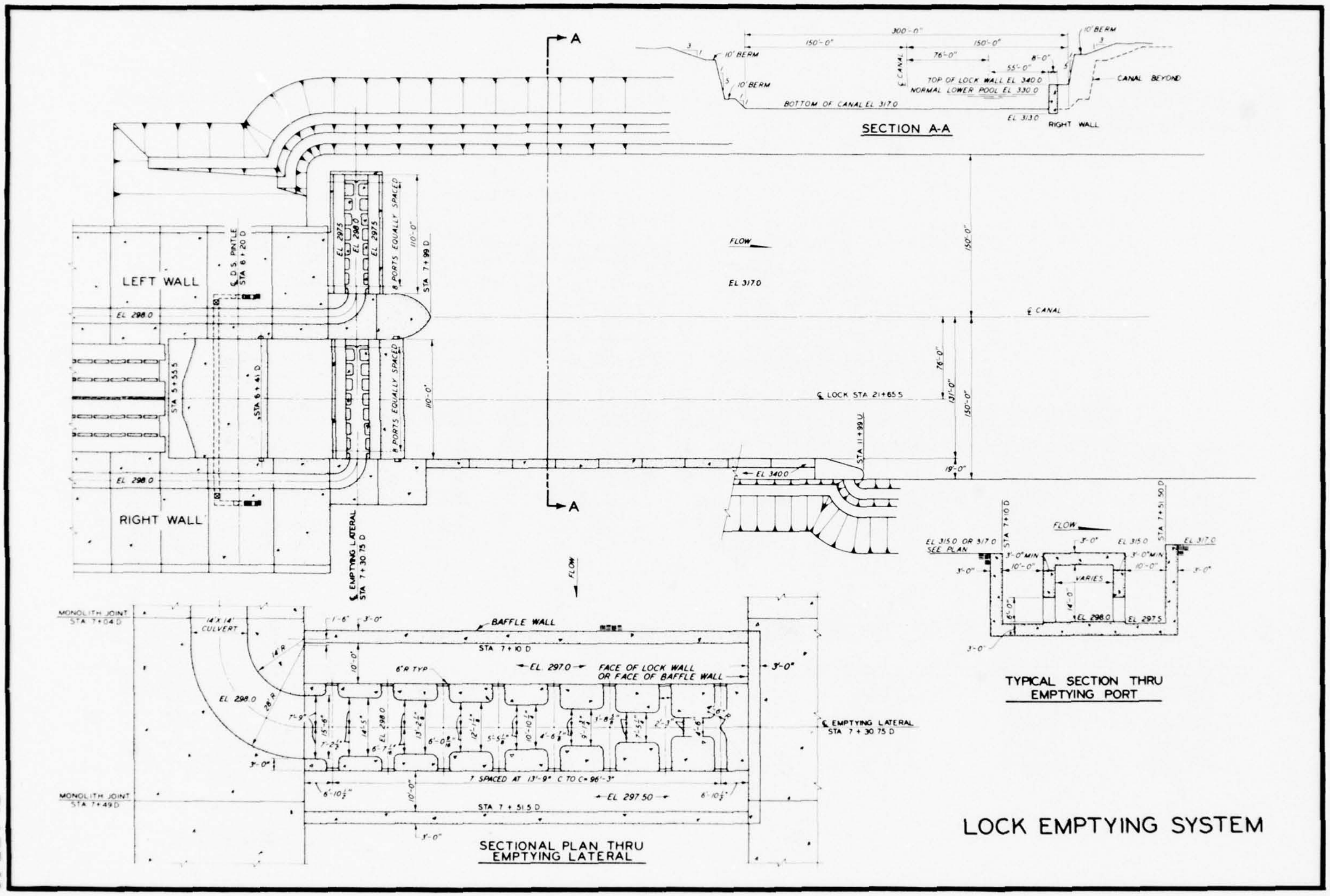
NORMAL (2) VALVE OPERATION



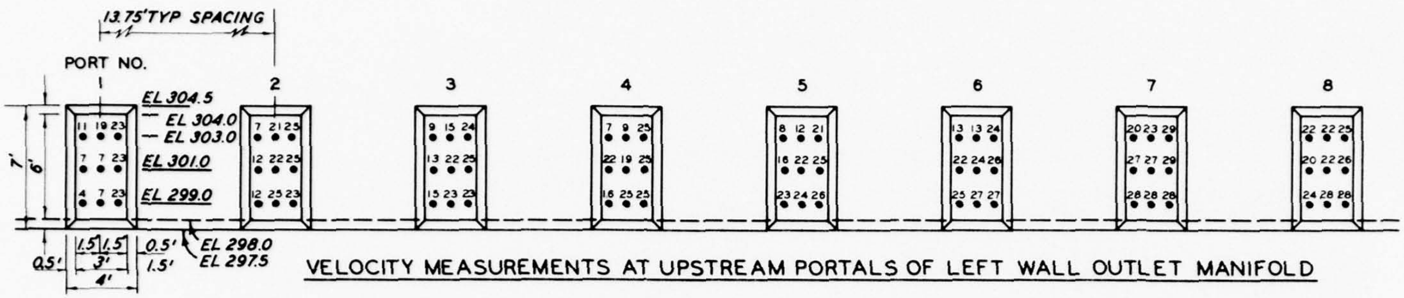
SINGLE (RIGHT) VALVE OPERATION

NOTE: 84-FT LIFT (UPPER POOL EL 414; LOWER POOL EL 330)

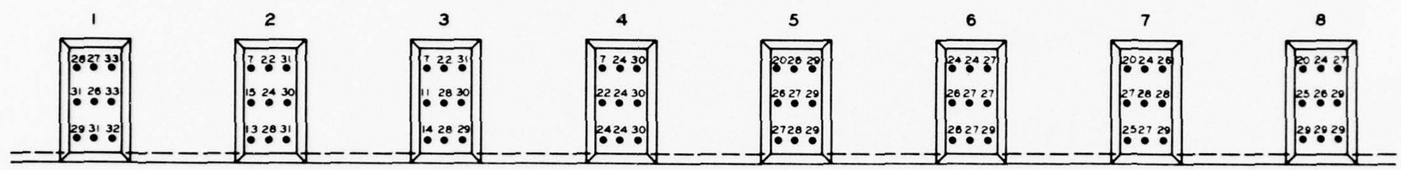
FILLING AND EMPTYING TIMES VERSUS VALVE TIME
TYPE I (ORIGINAL) DESIGN
NORMAL AND SINGLE VALVE OPERATIONS



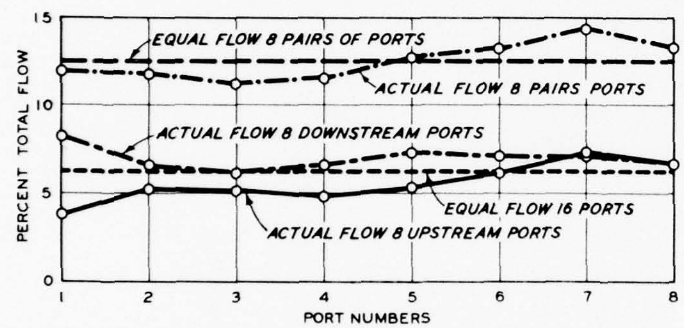
LOCK EMPTYING SYSTEM



VELOCITY MEASUREMENTS AT UPSTREAM PORTALS OF LEFT WALL OUTLET MANIFOLD



VELOCITY MEASUREMENTS AT DOWNSTREAM PORTALS OF LEFT WALL OUTLET MANIFOLD



COMPARISON OF PAIRS AND INDIVIDUAL PORT FLOW DISTRIBUTION
LEFT CULVERT OUTLET

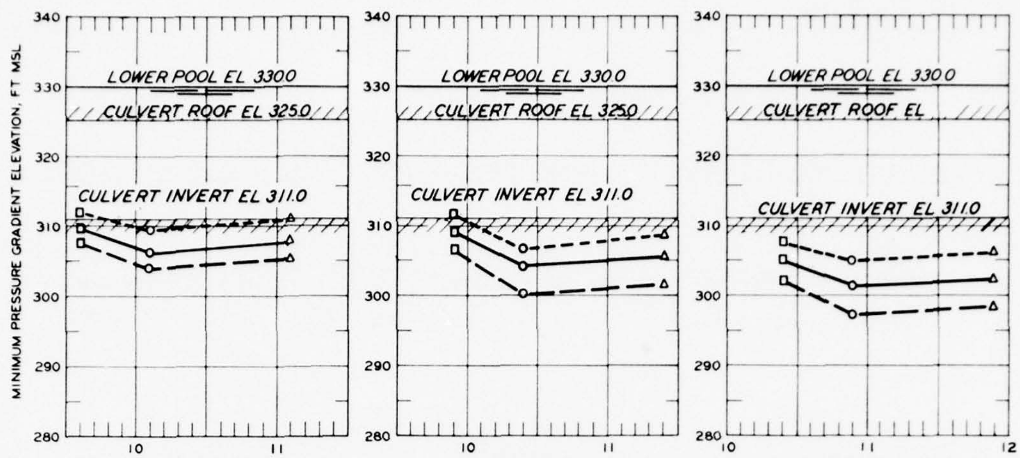
STEADY-FLOW TEST CONDITIONS

UPPER MITER GATES OPEN
FILL VALVES CLOSED
LOWER MITER GATES CLOSED
EMPTYING VALVES OPEN FULL
UPPER POOL 407.2
LOWER POOL 330.0

NOTE: VELOCITIES IN FEET PER SECOND

VELOCITIES AND FLOW DISTRIBUTION
AT OUTLET PORTS (LEFT CULVERT)

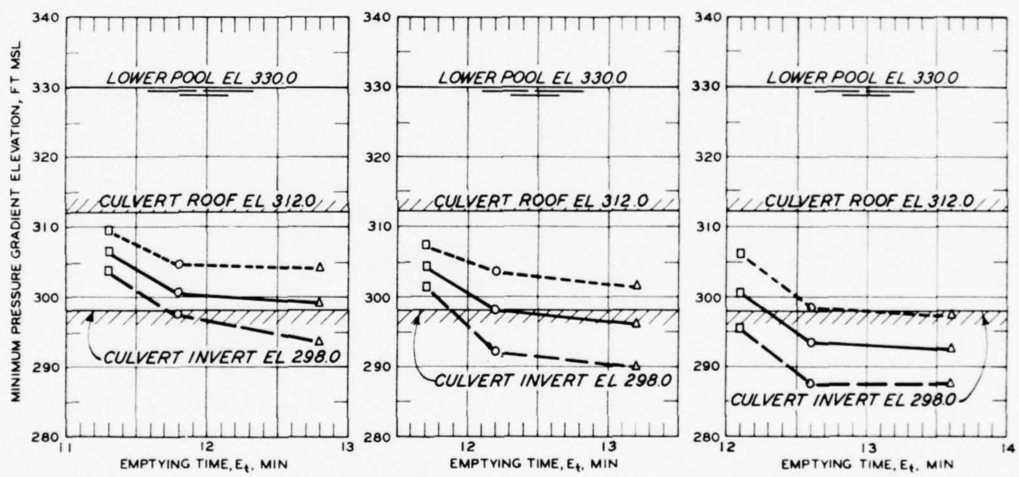
TYPE 2 DESIGN
STEADY-FLOW CONDITIONS



78-FT (MINIMUM) LIFT   84-FT (NORMAL) LIFT   92-FT (MAXIMUM) LIFT

NOTE: BULKHEAD SLOTS AND AIR VENTS DOWNSTREAM OF FILLING VALVES SEALED.
PRESSURE CELL ON CENTER LINE OF CULVERT ROOF AT STA 1+35.504.

FILLING VALVES



78-FT (MINIMUM) LIFT   84-FT (NORMAL) LIFT   92-FT (MAXIMUM) LIFT

NOTE: BULKHEAD SLOTS AND AIR VENTS DOWNSTREAM OF FILLING AND EMPTYING VALVES SEALED.
PRESSURE CELLS ON CENTER LINE OF CULVERT ROOF AT STA 1+35.50 AND 5+19.02D

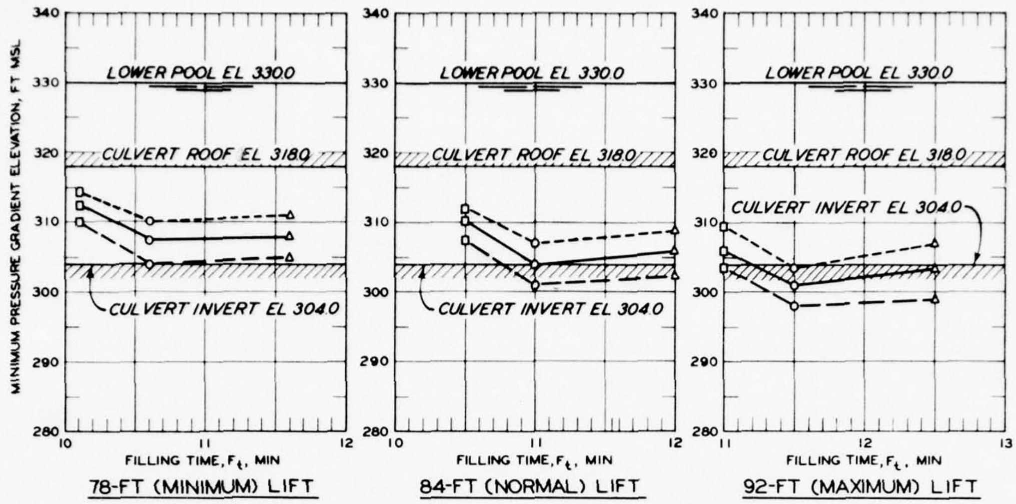
EMPTYING VALVES

LEGEND

SYMBOL	VALVE TIME MIN
□	1
○	2
△	4
-----	HIGH
——	OBSERVED AVG
— —	LOW

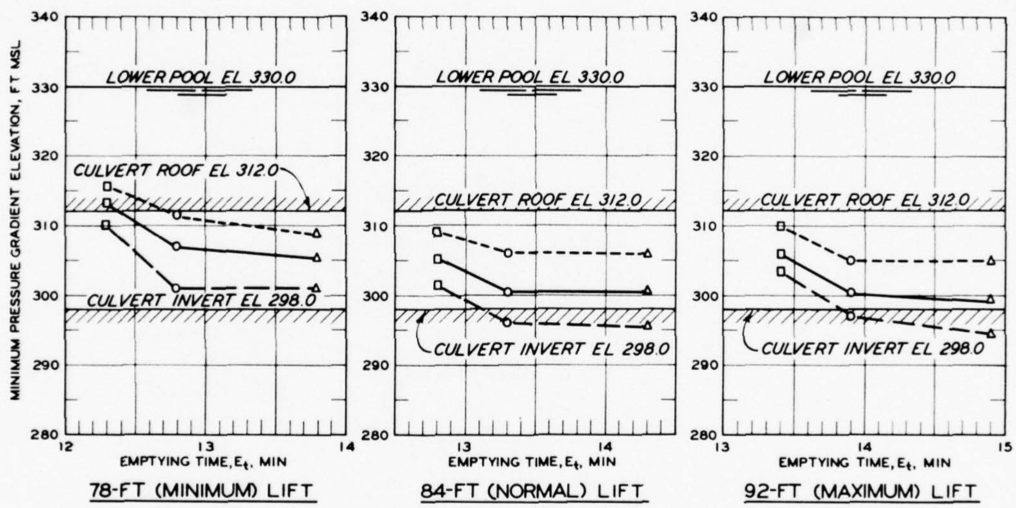
CULVERT ROOF PRESSURES DOWNSTREAM OF FILLING AND EMPTYING VALVES

TYPE I (ORIGINAL) DESIGN
NORMAL VALVE OPERATIONS
78-, 84-, AND 92-FT LIFTS



NOTE: BULKHEAD SLOTS AND AIR VENTS DOWNSTREAM OF FILLING VALVES SEALED.
PRESSURE CELL ON CENTER LINE OF CULVERT ROOF AT STA 0+62.55 D.

FILLING VALVES



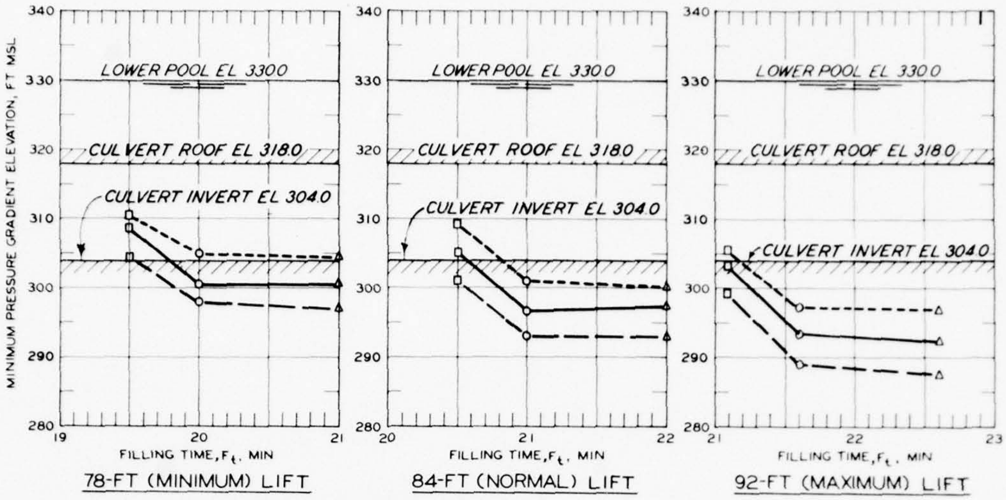
NOTE: BULKHEAD SLOTS AND AIR VENTS DOWNSTREAM OF EMPTYING VALVES SEALED.
PRESSURE CELLS ON CENTER LINE OF CULVERT ROOF AT STA 1+35.50 AND 5+19.02D

EMPTYING VALVES

LEGEND

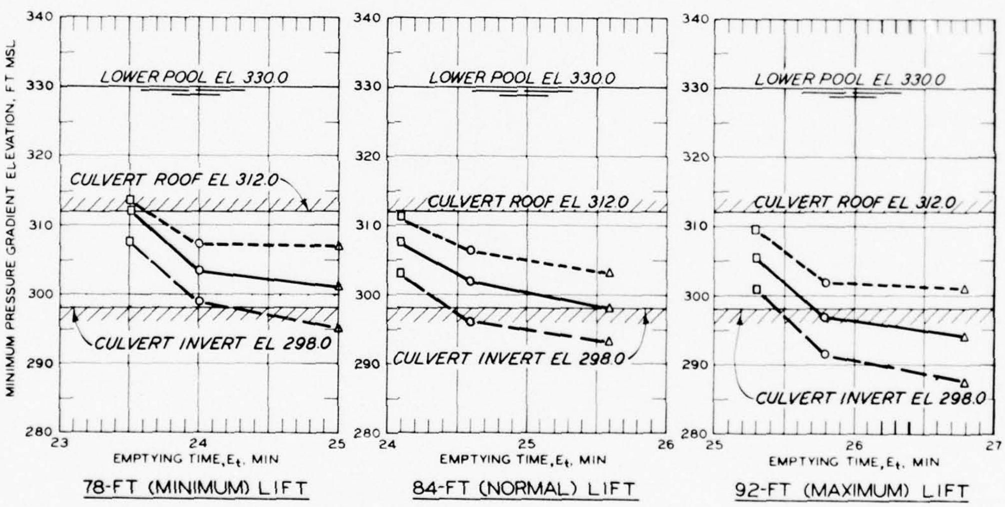
SYMBOL	VALVE TIME MIN
□	1
○	2
△	4
----	HIGH
——	OBSERVED AVG
— —	LOW

CULVERT ROOF PRESSURES DOWNSTREAM OF FILLING AND EMPTYING VALVES
TYPE 17 (RECOMMENDED) DESIGN
NORMAL VALVE OPERATIONS
78-, 84-, AND 92-FT LIFTS



NOTE: BULKHEAD SLOTS AND AIR VENTS DOWNSTREAM OF FILLING VALVES SEALED.
PRESSURE CELL ON CENTER LINE OF CULVERT ROOF AT STA 0+62.55 D.

FILLING VALVES



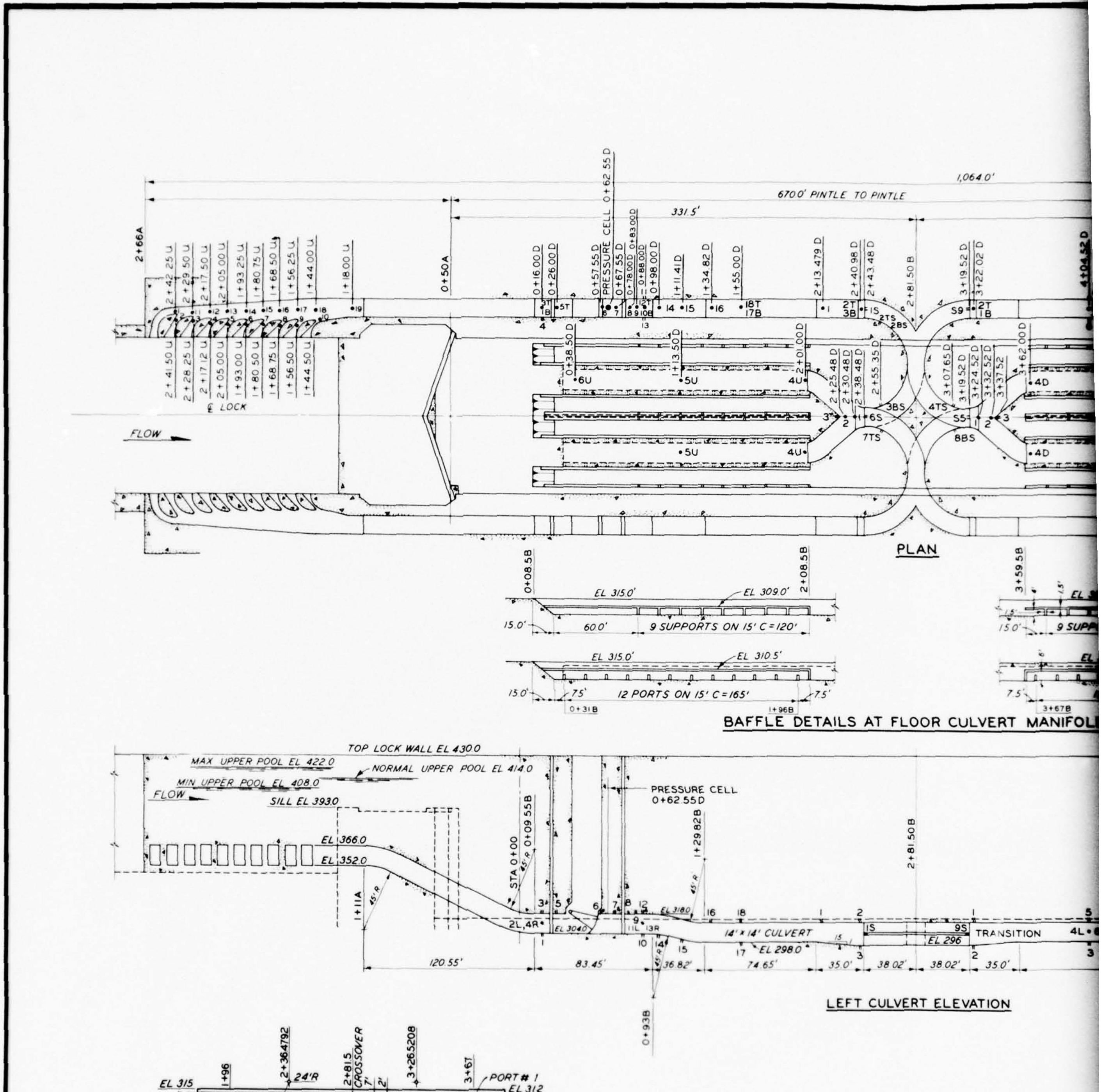
NOTE: BULKHEAD SLOTS AND AIR VENTS DOWNSTREAM OF EMPTYING VALVES SEALED.
PRESSURE CELL ON CENTER LINE OF CULVERT ROOF AT STA 5+19.02.

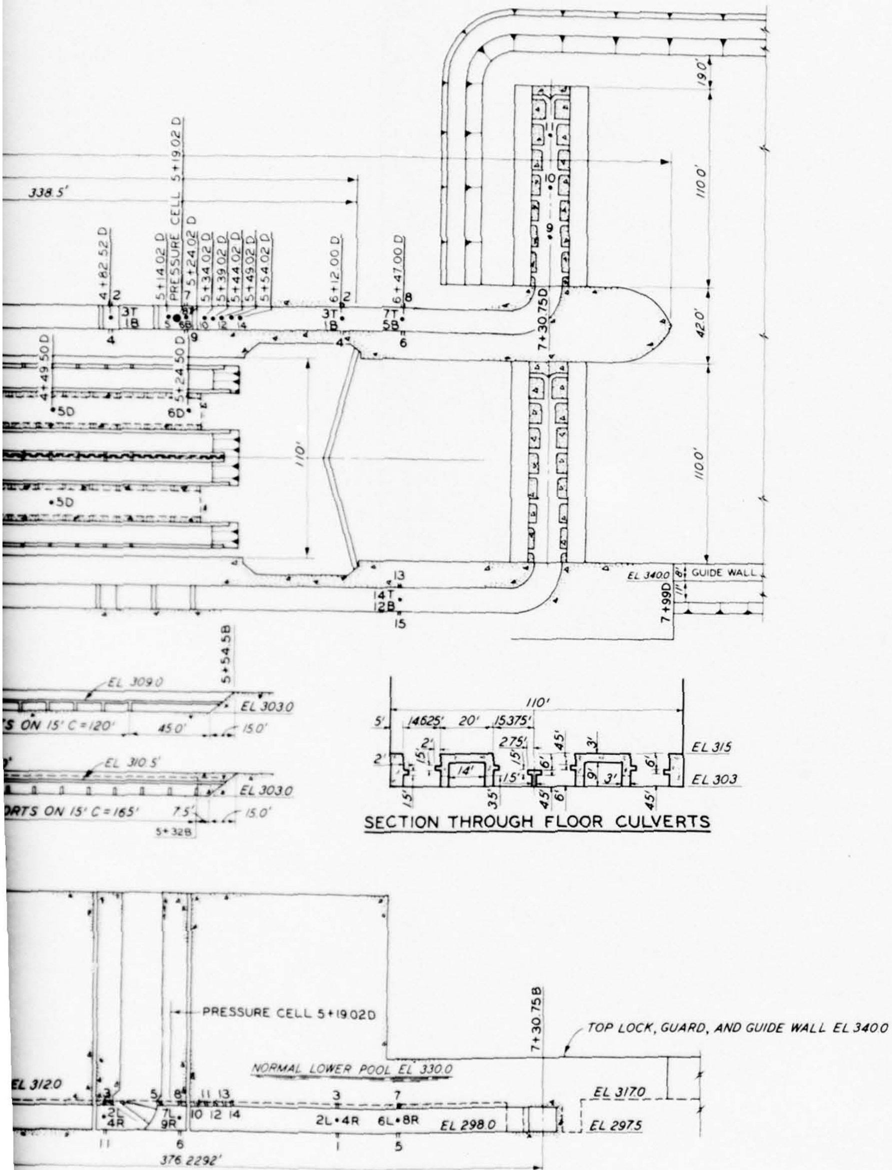
EMPTYING VALVES

LEGEND

SYMBOL	VALVE TIME MIN
□	1
○	2
△	4
-----	HIGH
———	OBSERVED AVG
— —	LOW

CULVERT ROOF PRESSURES DOWNSTREAM OF FILLING AND EMPTYING VALVES
TYPE 17 (RECOMMENDED) DESIGN
SINGLE (LEFT) VALVE OPERATIONS
78-, 84-, AND 92-FT LIFTS

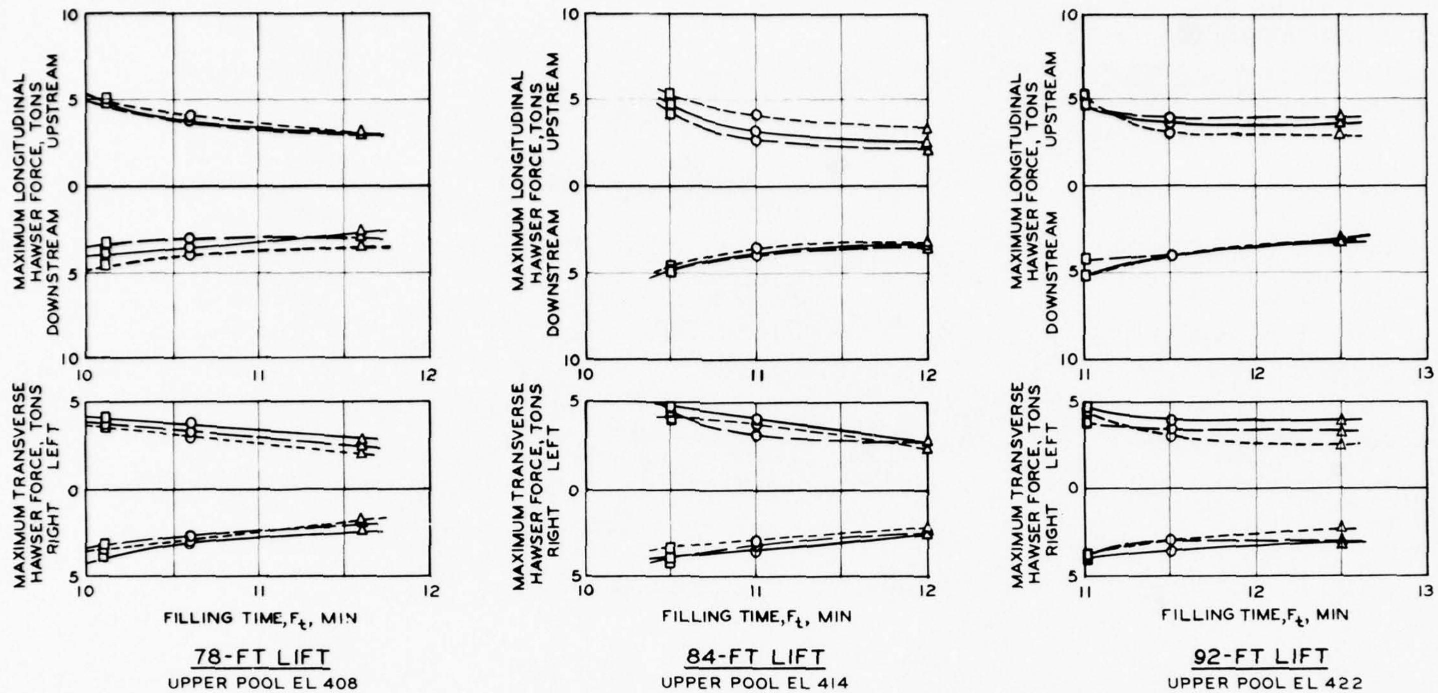

1,064.0'
670.0' PINTLE TO PINTLE
331.5'
PRESSURE CELL 0+62.55 D
FLOW
℄ LOCK
PLAN
EL 315.0'
EL 309.0'
60.0'
9 SUPPORTS ON 15' C=120'
EL 310.5'
12 PORTS ON 15' C=165'
BAFFLE DETAILS AT FLOOR CULVERT MANIFOL
TOP LOCK WALL EL 430.0
MAX UPPER POOL EL 422.0
NORMAL UPPER POOL EL 414.0
MIN UPPER POOL EL 408.0
SILL EL 393.0
EL 366.0
EL 352.0
PRESSURE CELL
0+62.55D
14' × 14' CULVERT
EL 298.0
EL 296
TRANSITION
120.55'
83.45'
36.82'
74.65'
35.0'
38.02'
LEFT CULVERT ELEVATION
EL 315
CROSSOVER
PORT # 1
EL 312
EL 305
EL 296
EL 303
38.0208'
33.4792
SECTION THROUGH CROSSOVER AND TUNING FORKS



PIEZOMETER LOCATIONS FILLING AND EMPTYING SYSTEM TYPE 17

RECOMMENDED DESIGN

2



LEGEND

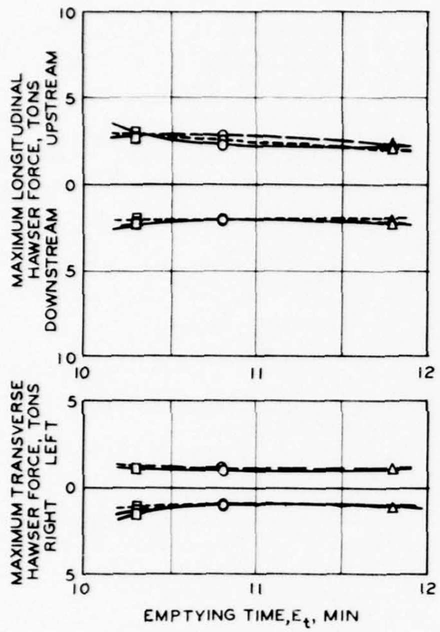
SYMBOL	VALVE TIME MIN
□	1
○	2
△	4

—— TOW POSITION 1
— — TOW POSITION 2
---- TOW POSITION 4

NOTE: BULKHEAD SLOTS DOWNSTREAM OF FILLING VALVES SEALED.
LOWER POOL EL 330.

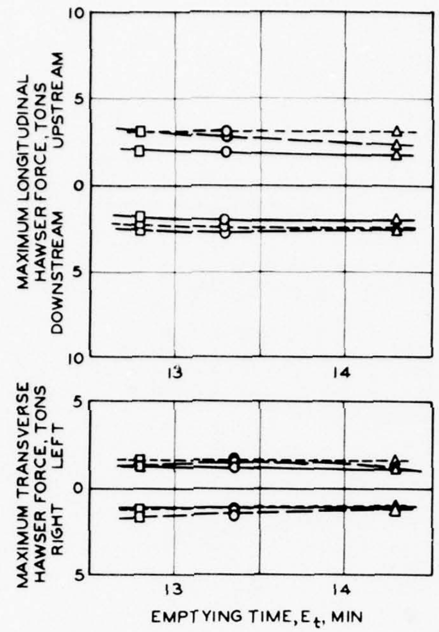
MAXIMUM HAWSER FORCES DURING FILLING OPERATIONS

TYPE 17 (RECOMMENDED) DESIGN
78-, 84-, AND 94-FT LIFTS



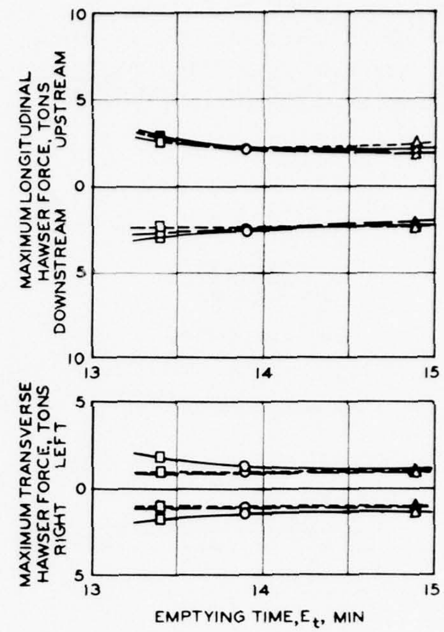
78-FT LIFT

UPPER POOL EL 408



84-FT LIFT

UPPER POOL EL 414



92-FT LIFT

UPPER POOL EL 422

LEGEND

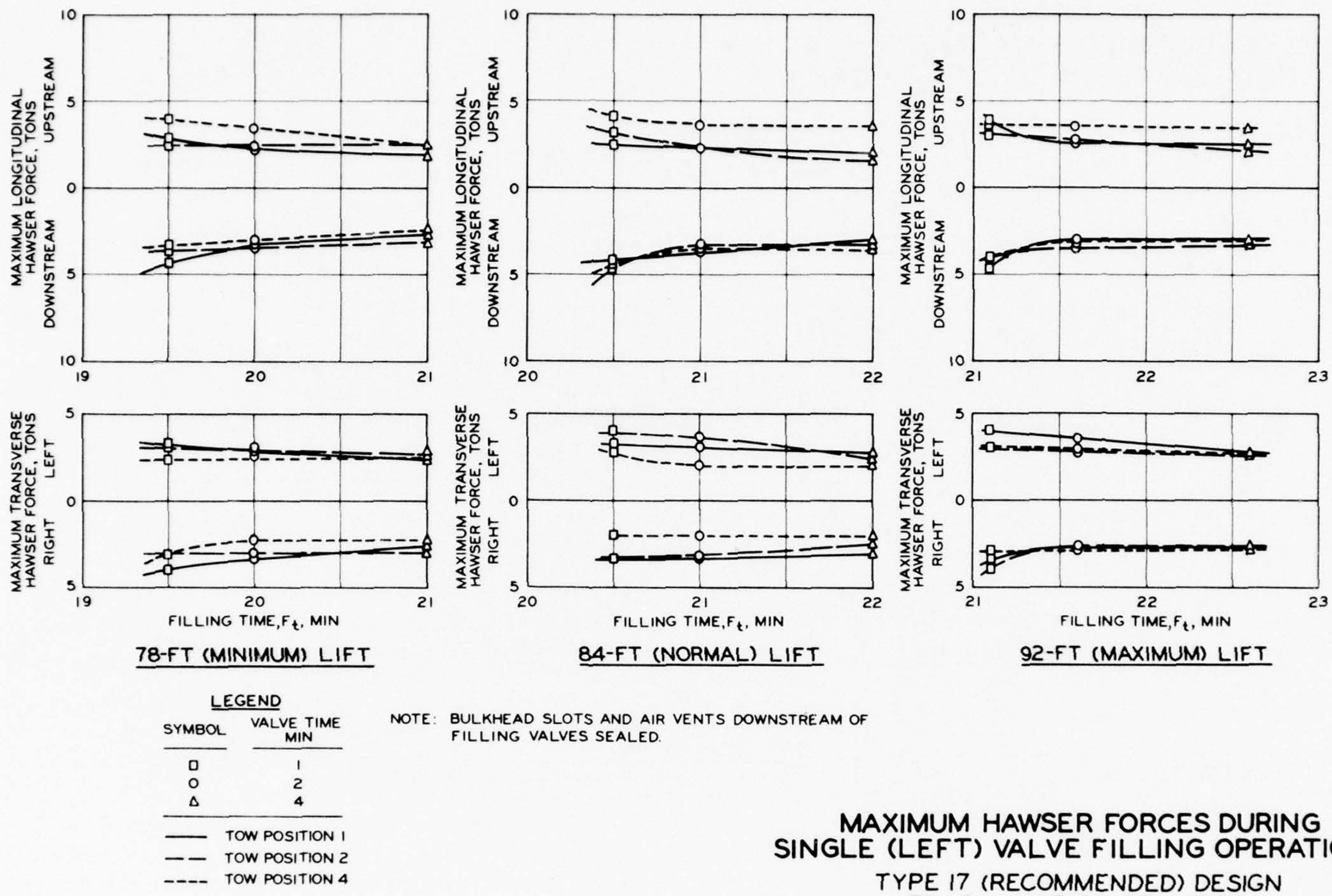
SYMBOL	VALVE TIME MIN
□	1
○	2
Δ	4

—— TOW POSITION 1
— — TOW POSITION 2
---- TOW POSITION 4

NOTE: BULKHEAD SLOTS DOWNSTREAM OF EMPTYING VALVES SEALED.
LOWER POOL EL 330.

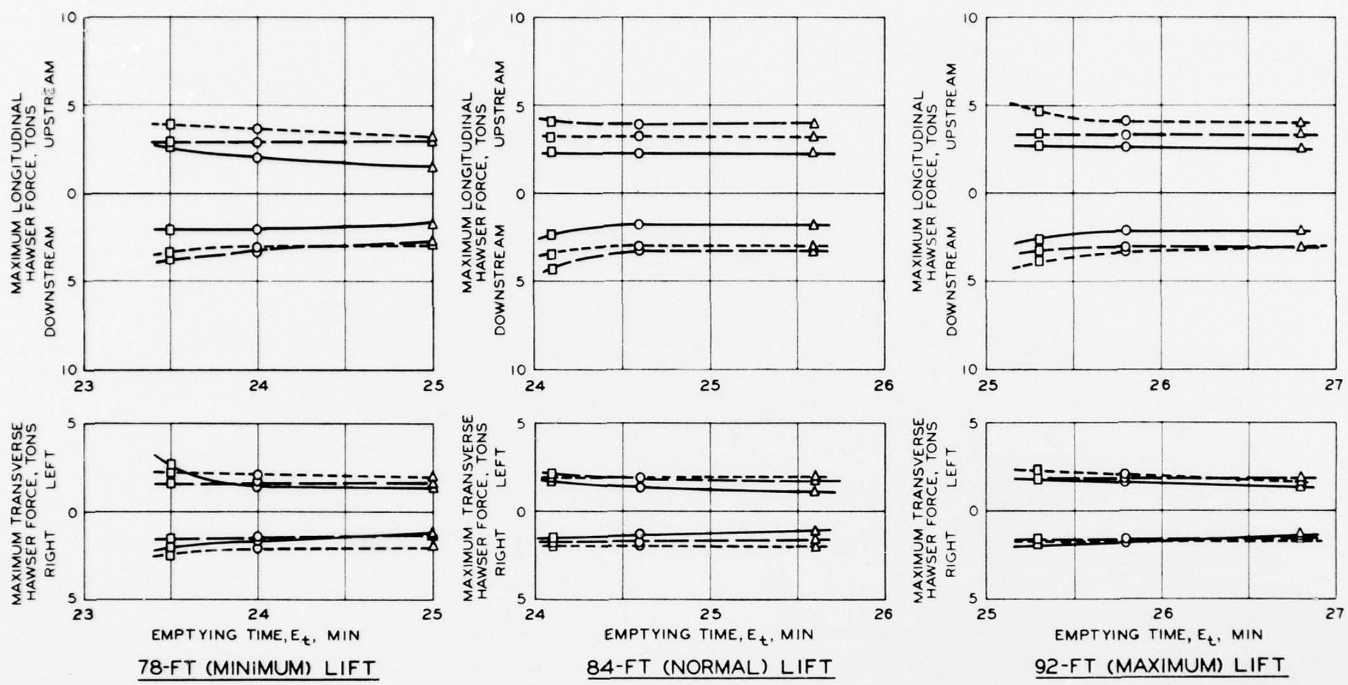
MAXIMUM HAWSER FORCES DURING EMPTYING OPERATIONS

TYPE 17 (RECOMMENDED) DESIGN
78-, 84-, AND 94-FT LIFTS



MAXIMUM HAWSER FORCES DURING
SINGLE (LEFT) VALVE FILLING OPERATIONS

TYPE 17 (RECOMMENDED) DESIGN
78-, 84-, AND 92-FT LIFTS



LEGEND

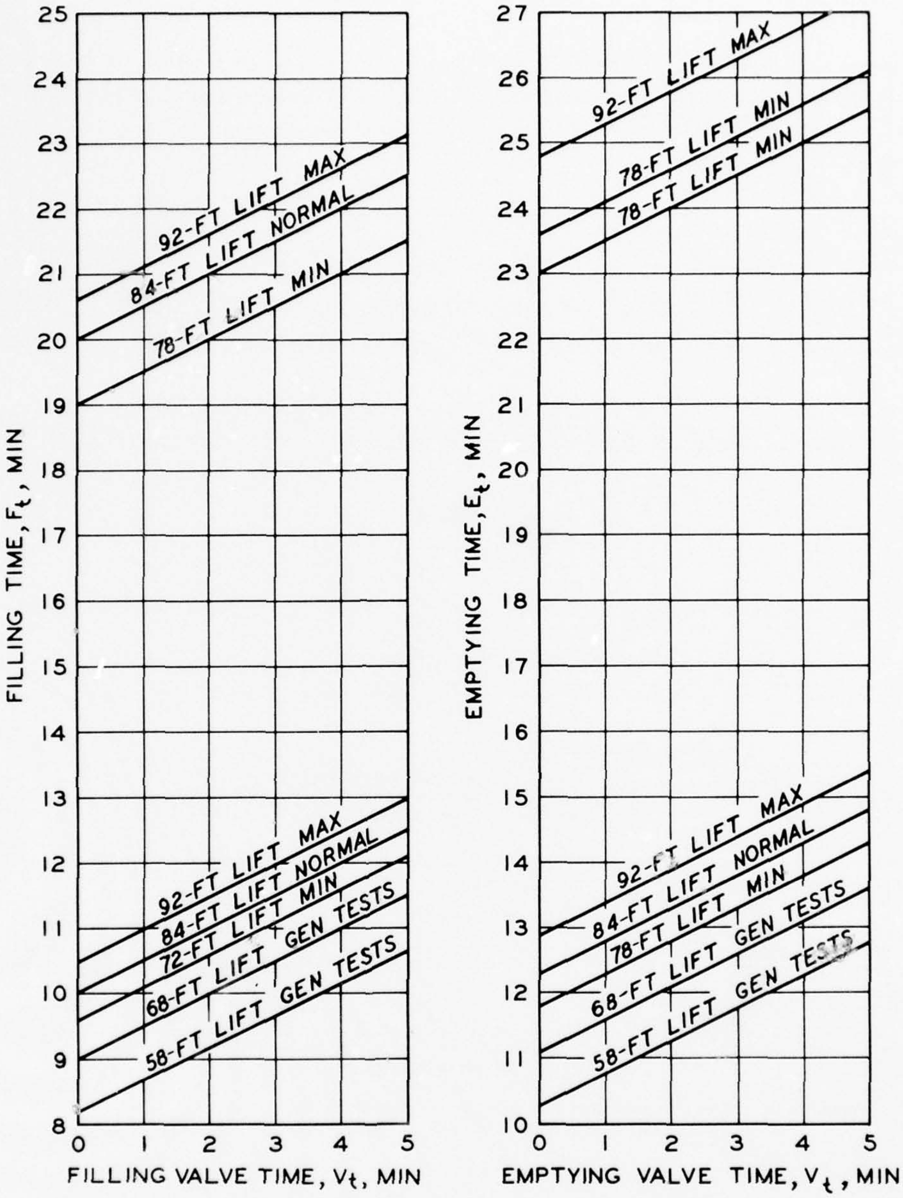
SYMBOL	VALVE TIME MIN
□	1
○	2
△	4

——— TOW POSITION 1
— — TOW POSITION 2
- - - - TOW POSITION 4

NOTE: BULKHEAD SLOTS AND AIR VENTS DOWNSTREAM OF EMPTYING VALVES SEALED.

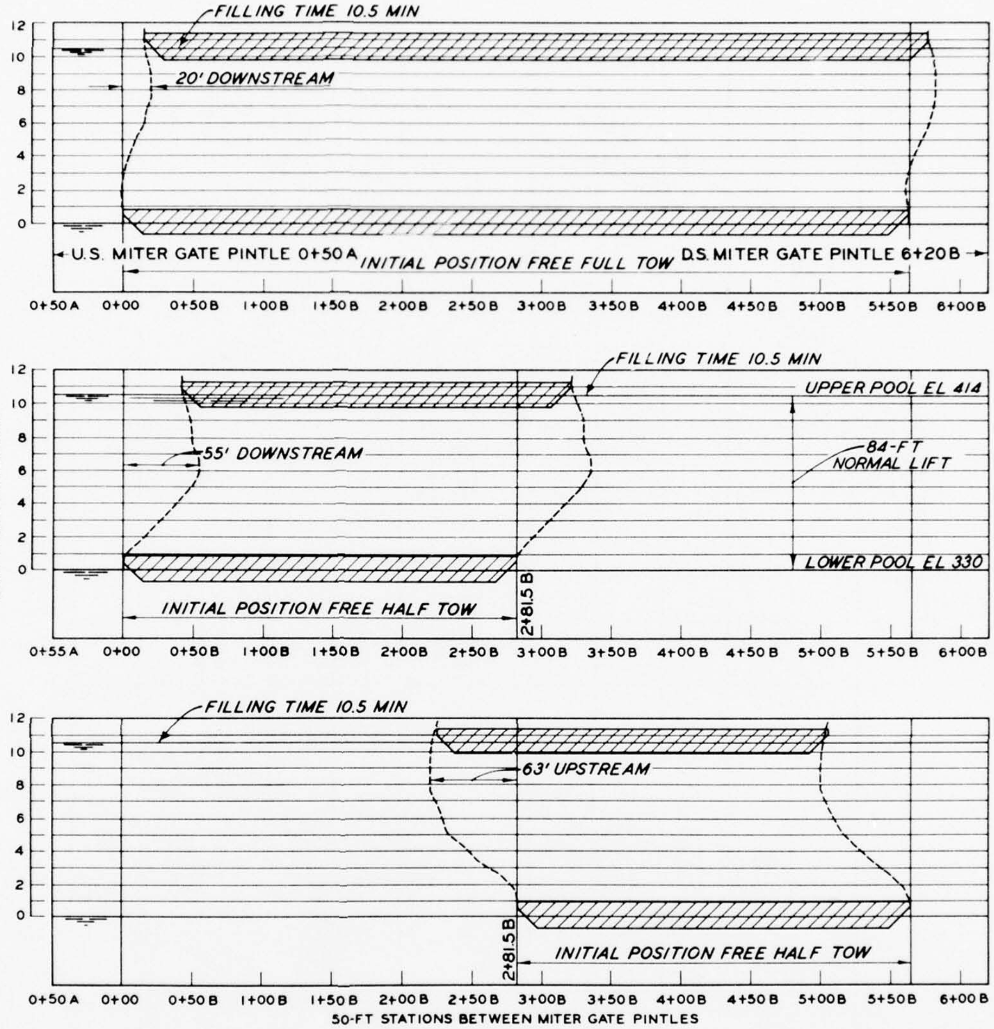
MAXIMUM HAWSER FORCES DURING SINGLE (LEFT) VALVE EMPTYING OPERATIONS

TYPE 17 (RECOMMENDED) DESIGN
78-, 84-, AND 92-FT LIFTS



FILLING AND EMPTYING TIMES VERSUS VALVE TIME NORMAL AND SINGLE VALVE OPERATIONS

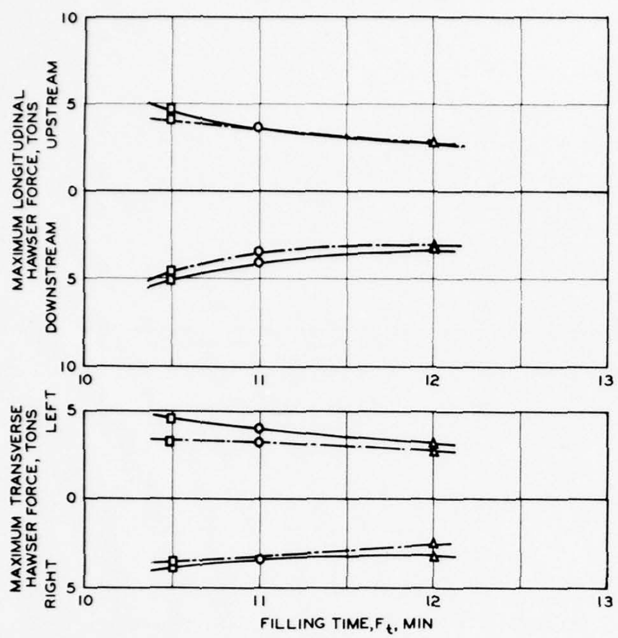
TYPE 17 (RECOMMENDED) DESIGN



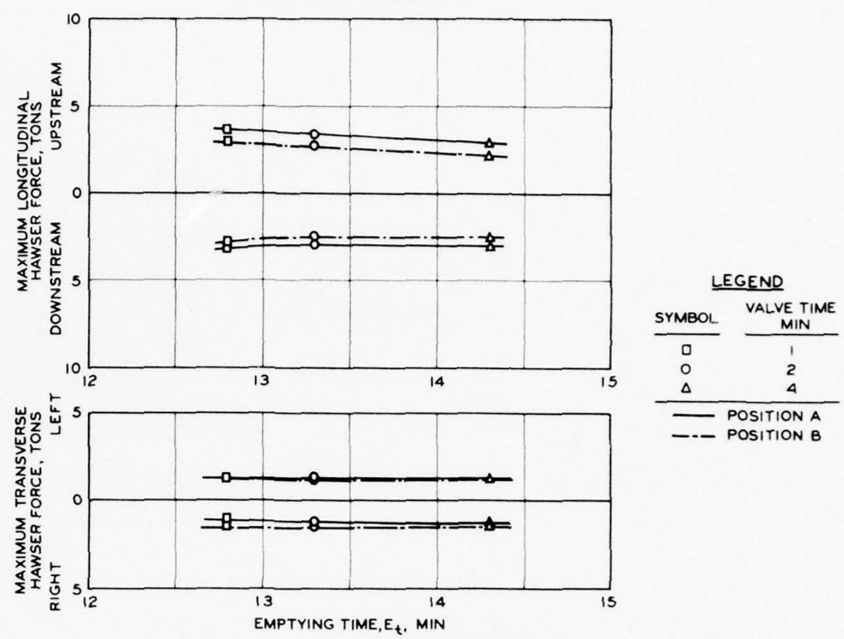
NOTE: FULL (8 BARGE) TOW AT 9-FT DRAFT HAS 15,105-TON DISPLACEMENT.
HALF (4 BARGE) TOW AT 9-FT DRAFT HAS 7,240-TON DISPLACEMENT.

TYPICAL FREE TOW MOVEMENT
DURING FILLING OPERATIONS
TYPE 17 (RECOMMENDED) DESIGN
1-MIN VALVE TIME
84-FT NORMAL LIFT

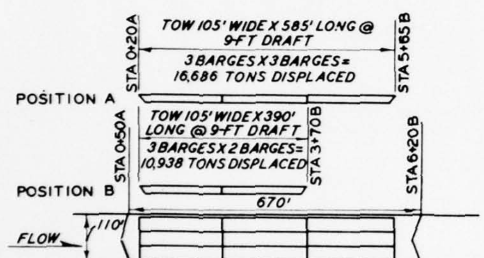
FILLING OPERATION



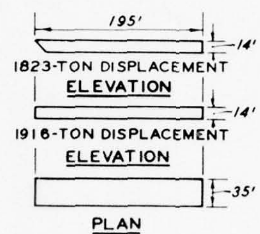
EMPTYING OPERATION



NOTE: 84-FT LIFT (UPPER POOL EL 414, LOWER POOL EL 330)
BULKHEAD SLOTS AND AIR VENT DOWNSTREAM OF FILLING AND EMPTYING VALVES SEALED.



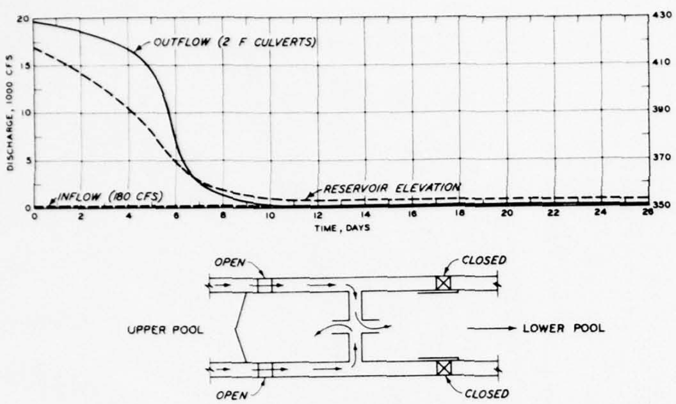
LOCK AND TOW ARRANGEMENT

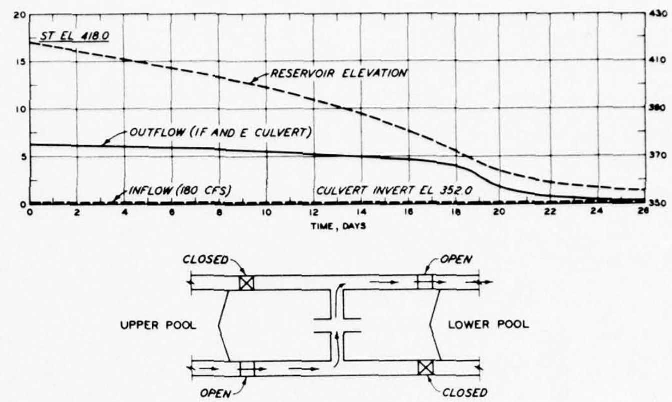


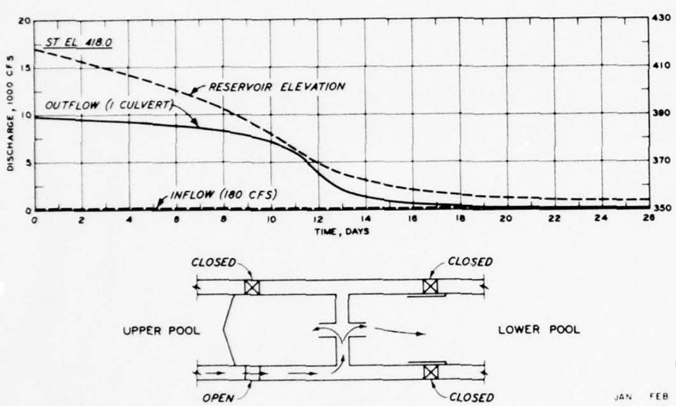
DETAILS OF 35'X195' BARGES DISPLACEMENTS FOR 9-FT DRAFT

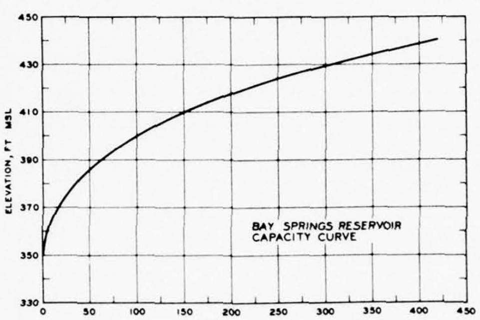
MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS WITH 105-FT-WIDE BARGE TOWS

TYPE 17 (RECOMMENDED) DESIGN
NORMAL 84-FT LIFT









GENERAL NOTES

1. REFERENCE ER 1110-2-50 (22 AUGUST 1975)
2. EMERGENCY PLAN OF OPERATION
   BLOCK DIVIDE IN THE VICINITY OF PADEN
   MOBILIZATION TIME = 4 DAYS
   DIVIDE CUT PLUG CONSTRUCTION TIME = 4 DAYS
   TOTAL MOBILIZATION AND CONSTRUCTION TIME = 8 DAYS
3. EMERGENCY DRAWDOWN BASED ON THE FOLLOWING CRITERIA
   a. STARTING POOL ELEVATION = 418 (TOP GATES AT PICKWICK DAM)
   b. INFLOW = 180 CFS (AVERAGE CONSECUTIVE 4 MONTHS INFLOW)
   c. MINIMUM TARGET ELEVATION = 374.0 (ELEV AT WHICH STORAGE IN THE RESERVOIR IS 10% OF THAT AT STARTING POOL ELEV OF 418.0)
   d. TIME TO REACH TARGET ELEVATION = 4 MONTHS
4. DRAWDOWN TIME = MOBILIZATION AND CONSTRUCTION TIME + EVACUATION TIME

MACKEYS CREEK NEAR DENNIS, MISSISSIPPI
(AVERAGE DISCHARGE IN CFS - 37 YR OF RECORD)

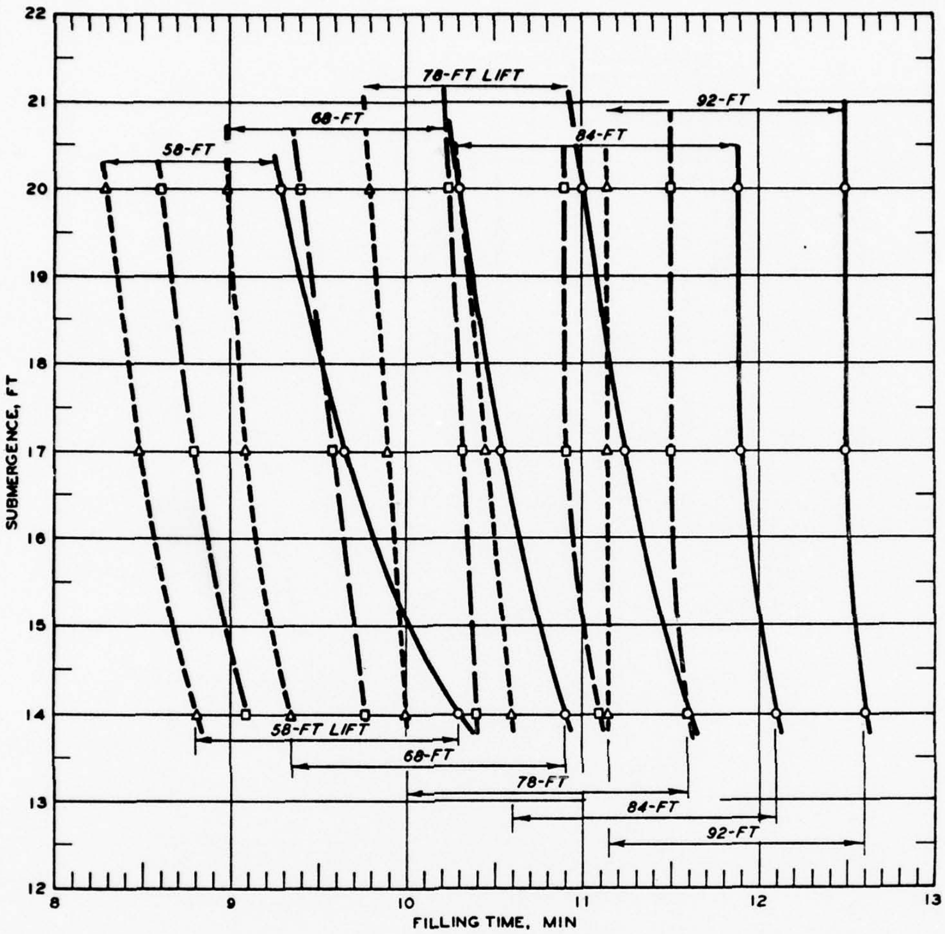
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
163	194	208	155	103	66	48	41	43	39	27	120

HIGHEST CONSECUTIVE 4-MONTH INFLOW

JAN	163 CFS
FEB	194 CFS
MAR	208 CFS
APR	155 CFS
	720 CFS

AVG = $\frac{720}{4}$ = 180 CFS

EMERGENCY DRAWDOWN DATA



LEGEND

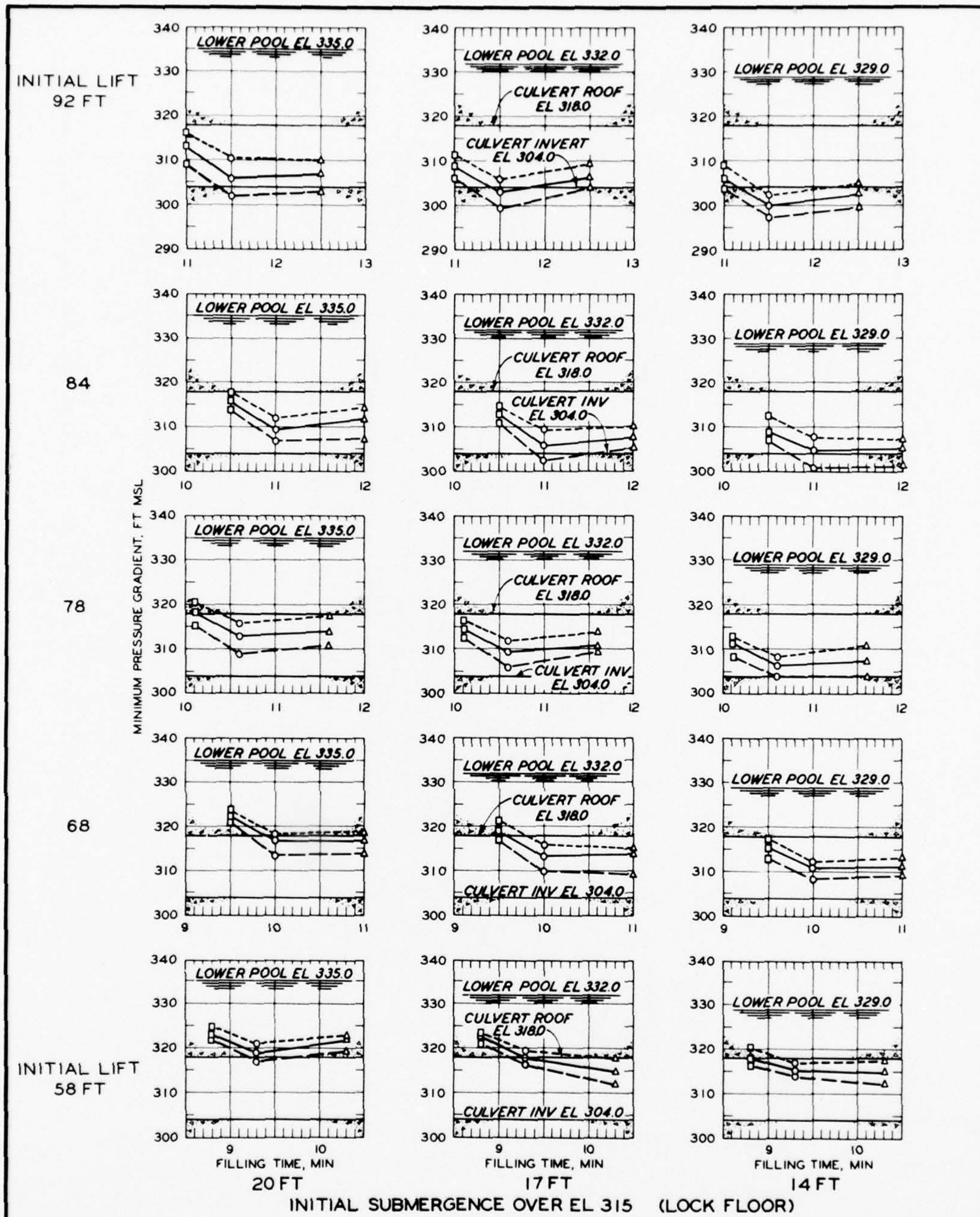
SYMBOL	HAWSER FORCE TONS
△- - -△	5
□— —□	4
○——○	3

NOTE: HAWSER FORCES WERE MEASURED ON 4-BARGE TOW AT 9-FT DRAFT (7240-TON DISPLACEMENT) IN POSITION 4, SEE PLATE 4.

SUBMERGENCE IS THE DIFFERENCE IN ELEVATION BETWEEN LOWER POOL AND CHAMBER FLOOR AT EL 315 (EXTERIOR ROOF OF FLOOR CULVERT AND CHAMBER FLOOR HAVE COMMON EL 315).

FILLING TIMES FOR 3-, 4-, AND 5-TON HAWSER FORCE LIMITS

TYPE 17 (RECOMMENDED) SYSTEM



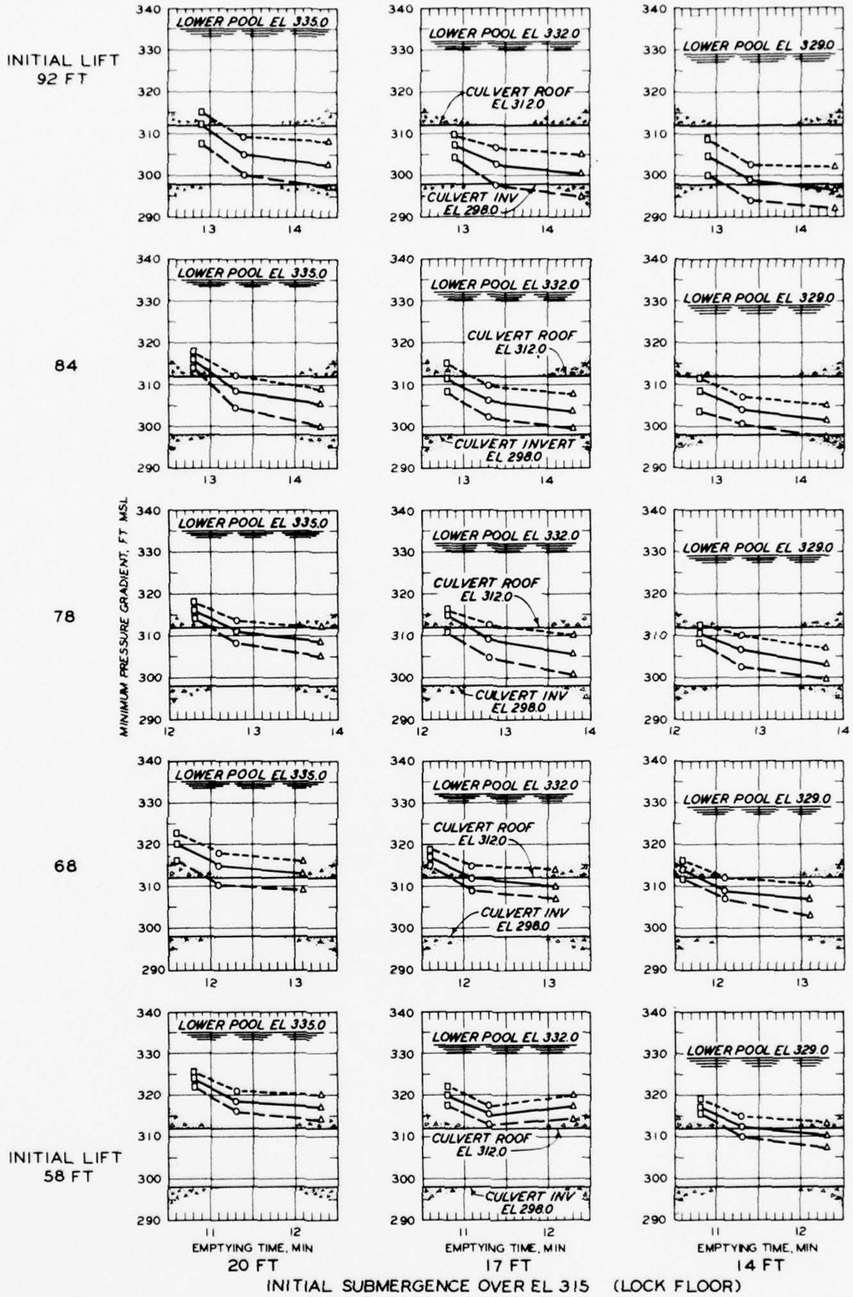
NOTE: PRESSURE CELL ON CENTER LINE OF CULVERT ROOF AT STA 0+62.55D.
BULKHEAD SLOTS DOWNSTREAM OF FILLING VALVES SEALED.

LEGEND

SYMBOL	VALVE TIME MIN
□	1
○	2
△	4
-----	HIGH
———	OBSERVED AVG
— —	LOW

EFFECT OF INITIAL SUBMERGENCE OVER LOCK FLOOR ON MINIMUM PRESSURES DOWNSTREAM OF FILLING VALVE

TYPE 17 (RECOMMENDED)
INITIAL LIFTS 92, 84, 78, 68, AND 58 FT



NOTE PRESSURE CELL ON CENTER LINE OF CULVERT ROOF AT STA 5+19.02

BULKHEAD SLOTS DOWNSTREAM OF EMPTYING VALVES SEALED

SYMBOL	VALVE TIME MIN
□	1
○	2
△	4
-----	HIGH
——	OBSERVED AVG
— —	LOW

EFFECT OF INITIAL SUBMERGENCE OVER LOCK FLOOR ON MINIMUM PRESSURES DOWNSTREAM OF EMPTYING VALVE

TYPE 17 (RECOMMENDED)
INITIAL LIFTS 92, 84, 78, 68, AND 58 FT

APPENDIX A: EFFECT OF LOWERING CULVERT FILLING VALVES 6 FT

Introduction

1. A meeting was held at the Office, Chief of Engineers, on 29 June 1977 with representatives of the Nashville District, South Atlantic Division, Ohio River Division, and the Waterways Experiment Station concerning the subject lock. It was decided at the meeting that the lock culvert invert at the filling valves would be lowered from el 304 to el 298 and that these changes would be incorporated in the existing model to determine if there would be any adverse effects and, if so, what modifications would be required to correct them. The downstream face of the filling valve well is at sta 1+00D. This change has been designated the type 18 filling system. The type 17 filling and emptying system with the filling valves at invert el 304 and the downstream face of the valve wells at sta 0+57.55 was developed and recommended for prototype adoption when previous model tests were completed during June 1976. The type 18 filling and emptying system was installed and was identical with the type 17 system beginning at sta 2+08.5 on the sidewall culverts. The modifications in the type 18 sidewall culverts upstream of sta 2+08.5 involved culvert invert grade, valve well position, culvert drop slope, and repositioning of the intake manifold upstream. Plate A1 is a schematic of the type 18 system and indicates piezometer locations and the pressure cell located on the roof of the culvert 7 ft downstream of the filling valve.

Tests and Results

2. Plate A2 is a plot of filling times versus valve time for normal and single (left) culvert operations. The culvert valves were opened according to the schedule shown in Plate 5 of the main text. Maximum hawser forces versus valve times for normal and single valve operations with 78-, 84-, and 92-ft lifts are plotted in Plates A3 and A4. With respect to turbulence and free tow movement in the lock

chamber during filling operations, conditions were about the same as those with the type 17 system previously recommended.

3. For comparative purposes, minimum pressures measured on the culvert roof downstream of the valves with both the type 17 and type 18 filling systems are plotted versus filling time in Plates A5 and A6. Past experience has shown that prototype values of pressure at the culvert roof downstream of the valves will be lower than model tests indicate. The average pressures measured on the culvert roof during filling with an 84-ft lift and 1-min valve time was -8 ft of water with the type 17 system and -5 ft of water with the type 18 system. With a 2-min valve time, the average pressures were -14 ft and -9.5 ft of water, respectively. Pressures observed in the model of Holt Lock were approximately -13 ft of water. With single valve operation in the model of Lower Granite Lock, pressures were less than -20 ft of water. Prototype tests indicate that neither of these structures experiences cavitation when air is admitted into the culvert. The prototype tests at Lower Granite Lock indicated that when an additional 5 ft of tailwater was present, cavitation booms were experienced before air began to be drawn into the culvert. Experience has shown that controlled admission of air will relieve cavitation pressures that would otherwise be -20 to -25 ft of water and that when valves are placed so low that air cannot be properly drawn into the culvert of high-lift locks, such as is the case at the John Day Lock, cavitation will occur.

4. Unless air is admitted, cavitation can be expected downstream of the filling valves with either the type 17 or the type 18 system. Admission of small quantities of air should cushion the collapse of vapor pockets and eliminate the likelihood for cavitation damage. Accurate laws for scaling air entrainment characteristics from model to prototype lock filling and emptying systems have not been established, and it is suggested that the amount of venting required for the prototype be established by field tests conducted by personnel of the Nashville District and the Waterways Experiment Station. Details for the prototype venting arrangement were suggested in paragraph 28 of the main text.

5. Qualitative tests in which air was admitted to this low pressure area were conducted to investigate the effect of this type operation on filling characteristics and minimum pressures with the type 18 system installed. Two 12.5-in.-diam air vents were installed 7 ft downstream of the valve seal point and adjacent to (left and right) the pressure cell at sta 1+05D. Tests were conducted with one or two vents open as well as with one vent closed and the other throttled by inserting a "cork" or 2.5-ft-long orifice or short tube with an inside diameter ranging from 1-29/32 to 9 in. (See Plate A7 and Table A1.) Table A1 shows the period of negative pressure existing on the culvert roof with and without air venting. A typical pressure cell record versus a 1-min valve without air is shown at the bottom of Table A1. The qualitative effect of air venting on the culvert roof pressures downstream of the filling valves for 1- and 2-min valve schedules is plotted in Plate A7. With respect to other filling characteristics, filling times were increased by no more than one tenth of a minute, and there was no significant effect on hawser forces with a half tow moored in position 4. Bubbles and slugs of air collected in the culvert filling system and some erupted into the chamber water surface. The filling and emptying system was carefully purged of air after each test. It is desirable that only as much air as can be entrained as small bubbles in the flow be admitted. When too much air is allowed to enter the culvert, air pockets will form and surges will result when these pockets are discharged into the lock chamber.

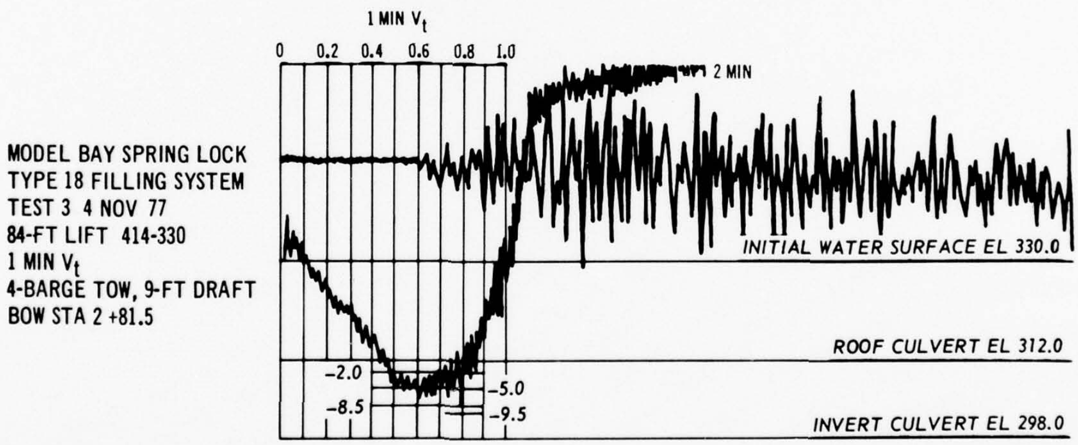
6. Pressures were observed at all piezometers in the type 18 filling system during both normal and single (left) culvert valve operations with a 1-min valve (Tables A2 and A3). Other than downstream from the valves, all pressures were positive, as was the case with the type 17 filling system. Thus the two systems are considered essentially equal, except for the degree to which air will be drawn in at the valves. Since cavitation has been experienced in the field only at those locks where no air or insufficient air is drawn into the system, the type 17 filling and emptying system with its lower pressures downstream from the valves is preferable to the type 18 system.

Table A1

Period of Negative Pressure on Culvert Roof Downstream of Filling Valve During Filling With and Without Air Venting, Type 18 Filling System

Record No. and Date		Lift ft	Valve Time V_t min	Filling Time ft, min	Air Vent or Orifice* No.	Diameter ft	Diameter in.	Period of Negative Pressure On Roof of Culvert: Begins min	Begins sec	Begins % Time	Ends min	Ends sec	Ends % Time
3	2 Nov 77	92	1	10.8	None			0	22	37	0	52	87
11	2 Nov 77		2	11.4	None			0	42	35	1	53	94
3	4 Nov 77	84	1	10.3	None			0	26	43	0	52	87
			2	10.9	None			0	42	36	1	48	90
			4	12.1	None			0	84	35	3	43	93
7	10 Nov 77	84	1	10.3	1 orifice	0	1-29/32	0	27	45	0	48	80
6	10 Nov 77		1	10.3	1 orifice	0	2-7/32	0	27	45	0	49	82
5	10 Nov 77		1	10.3	1 orifice	0	3	0	27	45	0	48	80
4	10 Nov 77		1	10.3	1 orifice	0	6	0	26	43	0	48	80
3	10 Nov 77		1	10.3	1 orifice	0	9	0	27	45	0	48	80
2	10 Nov 77		1	10.3	1 vent	1	0-1/2	0	27	45	0	49	82
1	10 Nov 77		1	10.3	2 vents	1	0-1/2	0	27	45	0	50	83
10	10 Nov 77	84	2	10.9	1 orifice	0	1-29/32	0	43	36	1	44	87
11			2	10.9	1 orifice	0	2-7/32	0	46	38	1	46	88
12	11 Nov 77		2	10.9	1 orifice	0	3	0	46	38	1	46	88
13			2	10.9	1 orifice	0	6	0	46	38	1	48	90
14			2	10.9	1 orifice	0	9	0	47	39	1	48	90
15			2	10.9	1 vent	1	0-1/2	0	48	40	1	48	90
16			2	10.9	2 vents	1	0-1/2	0	43	36	1	47	89

Note: Lower pool el 330.0 for all tests.
* In each culvert roof 7 ft downstream of filling valve.



TYPICAL DATA RECORD OF PRESSURE CELL RECORDING
(84-FT LIFE, 1-MIN VALVE, AND NO VENTING)

Table A2

Average Piezometer Readings During Filling, Type 18 Arrangement, 84-Ft Lift

Upper Pool El 414.0, Lower Pool El 330.0, Normal 1-Min Valve Operation

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water												
No.	Station	Elevation	T* = 15 LC** = 330.2	T = 30 LC = 331.1	T = 45 LC = 333.0	T = 60 LC = 335.9	T = 75 LC = 339.5	T = 90 LC = 343.3	T = 120 LC = 350.3	T = 150 LC = 357.5	T = 180 LC = 364.0	T = 210 LC = 369.9	T = 240 LC = 375.4	T = 300 LC = 385.3	T = 360 LC = 393
Intake (Left Wall)															
1	2+76.36U	352.0	414.1	413.3	411.9	409.1	406.6	406.1	406.7	407.1	407.6	408.1	408.7	409.8	410.9
2	2+75.61U	352.0	414.0	413.2	411.9	409.6	407.7	407.4	407.9	408.3	408.7	409.1	409.6	410.4	411.4
3	2+62.36U	352.0	413.9	412.8	410.8	406.7	403.2	403.1	403.9	404.8	405.7	406.6	407.2	408.7	410.2
4	2+51.23U	352.0	413.8	412.3	409.3	403.7	398.9	398.8	399.9	401.3	402.6	403.7	404.8	407.0	409.0
5	2+39.11U	352.0	413.7	412.1	409.2	403.8	399.4	399.2	400.4	401.7	402.9	404.0	405.0	407.1	409.1
6	2+27.11U	352.0	413.6	411.9	408.7	402.6	397.3	397.0	398.3	399.7	401.1	402.6	404.0	406.2	408.5
7	2+14.61U	352.0	413.3	411.3	407.0	399.3	392.7	392.4	394.1	396.0	398.0	399.7	401.5	404.3	407.3
8	2+02.86U	352.0	413.0	411.0	406.8	399.0	393.5	393.4	395.2	397.1	398.9	400.7	402.0	404.8	407.7
9	1+90.61U	352.0	413.2	411.0	406.6	398.3	391.6	391.0	392.9	394.9	396.9	398.9	400.6	403.9	406.9
10	1+78.61U	352.0	412.9	410.7	405.8	397.0	390.4	390.5	392.4	394.5	396.7	398.6	400.1	403.7	406.7
11	2+63.61U	352.0	413.9	412.9	410.9	407.2	404.3	404.3	404.9	405.8	406.5	407.2	400.8	409.0	410.6
12	2+51.61U	352.0	413.8	412.6	410.2	405.6	401.6	401.5	402.4	403.5	404.3	405.5	406.3	408.0	409.7
13	2+39.11U	352.0	413.7	412.3	409.4	403.9	399.4	399.2	400.3	401.6	402.8	404.0	405.0	407.0	409.0
14	2+27.36U	352.0	413.6	411.9	408.6	402.2	397.2	397.4	398.7	400.1	401.6	402.9	404.0	406.4	408.6
15	2+14.86U	352.0	413.3	411.5	407.6	400.3	394.8	395.0	396.6	398.3	399.8	401.4	402.8	405.5	407.9
16	2+02.61U	352.0	413.1	411.1	406.9	399.0	393.0	393.2	394.9	396.7	398.6	400.2	401.9	404.7	407.6
17	1+90.36U	352.0	412.9	410.8	406.2	397.8	391.6	391.7	393.7	395.7	397.6	399.3	401.0	404.1	407.0
18	1+78.11U	352.0	412.7	410.3	404.9	395.6	388.6	389.2	390.9	393.2	395.5	397.6	399.6	403.0	406.3
19	1+52.11U	352.0	411.9	408.6	399.9	396.1	375.6	376.0	379.4	363.0	387.5	389.8	392.9	398.0	402.9
Culvert Drop Section (Left Wall)															
1	1+29.11U	352.0	413.7	410.6	404.8	393.9	378.6	370.1	373.1	377.1	381.3	385.1	388.7	395.0	400.4
2	1+17.40U	350.0	413.4	409.7	403.0	390.3	372.7	362.9	365.9	372.0	375.7	380.2	383.5	391.9	398.2
3	1+05.70U	347.3	413.2	409.5	403.0	390.9	373.9	366.0	369.9	374.5	378.9	383.0	387.2	393.8	399.5
4	1+00.70U	345.2	413.1	409.5	403.8	392.4	377.7	370.8	374.0	378.0	383.0	385.9	389.3	395.6	400.8
5	0+34.0D	312.0	411.3	405.0	397.1	383.0	366.0	361.8	367.2	371.9	376.6	381.1	385.0	392.6	398.8
6	0+39.0D	312.0	411.3	405.0	397.6	383.7	367.4	363.6	368.9	373.3	377.9	383.5	386.7	393.3	399.3
Filling Valve (Left Wall)															
1	0+58.0D	298.0	406.1	403.1	390.7	372.2	363.0	365.2	370.0	374.6	379.2	385.2	387.1	393.9	400.0
2	0+58.0D	305.0	405.8	403.2	390.1	373.4	363.0	365.0	369.8	374.3	379.0	385.0	387.6	393.9	400.0
3	0+58.0D	312.0	406.9	403.6	391.9	373.8	363.1	364.9	369.8	374.3	378.9	384.9	387.0	393.7	399.9
4	0+58.0D	305.0	406.3	403.1	390.9	373.7	363.4	365.2	370.0	374.6	379.1	385.1	387.0	394.0	400.0
5	0+68.0D	312.0	405.4	402.9	389.3	370.6	362.5	364.9	369.9	374.4	379.0	385.0	387.0	393.8	399.9
6	1+00.00D	312.0	324.1	313.3	309.4	328.9	358.6	361.0	366.5	371.4	376.4	380.7	383.0	392.3	398.6
7	1+10.00D	312.0	323.6	312.8	309.4	329.6	360.1	362.0	367.5	372.2	377.1	381.3	385.6	392.7	399.3
8	1+21.50D	312.0	324.2	314.3	311.0	337.3	359.7	361.2	366.7	371.7	376.6	381.0	385.2	392.5	399.0
9	1+26.50D	312.0	324.4	315.1	314.3	342.0	359.7	361.4	366.9	371.8	376.7	381.1	385.3	392.6	399.1
10	1+31.50D	298.0	326.8	319.6	320.1	344.2	360.1	362.0	367.4	372.2	377.0	381.3	385.5	392.7	399.2
11	1+31.50D	305.0	326.0	319.3	317.6	341.2	359.2	361.7	367.0	371.9	376.8	381.2	385.4	392.4	399.0
12	1+31.50D	312.0	325.3	316.7	317.6	344.5	359.5	361.1	366.7	371.6	376.4	381.0	385.2	392.2	398.9
13	1+31.50D	305.0	325.2	318.0	319.0	344.5	360.0	361.9	367.3	372.0	377.0	381.3	385.6	392.6	398.0
14	1+41.50D	312.0	325.9	321.5	325.7	347.0	358.6	360.5	366.0	370.9	376.0	380.5	384.0	392.0	398.7
15	1+71.50D	312.0	335.4	335.4	338.1	348.9	356.9	359.5	365.0	370.0	375.1	379.7	383.0	391.8	398.4
16	1+99.00D	312.0	334.7	337.2	341.5	348.8	355.7	358.5	364.3	369.3	374.6	379.2	383.0	391.4	398.2
Transition to Crossover (Left Wall)															
1	2+13.48D	312.0	335.3	337.8	343.5	351.8	358.6	361.0	366.6	371.4	376.4	380.8	384.5	392.3	398.9
2	2+40.98D	312.0	334.3	337.1	342.8	351.8	359.8	362.8	368.0	372.8	377.6	381.7	385.7	393.0	399.2
3	2+40.98D	296.0	334.0	336.7	343.0	352.0	359.3	362.8	368.1	372.9	377.6	383.0	385.8	393.0	399.4
Crossover Culvert															
1S	2+43.48D	304.0	333.9	338.7	352.0	375.4	392.0	398.0	401.5	402.7	404.0	404.7	406.0	408.0	409.9
2TS	2+55.35D	308.5	332.7	333.0	330.9	328.9	328.0	328.4	333.8	341.4	349.8	351.4	364.8	377.1	388.0
2BS	2+55.35D	299.5	332.9	333.7	382.8	328.4	327.2	330.4	339.1	340.8	354.8	362.0	368.8	380.3	390.6
3BS	2+55.35D	299.5	331.7	332.3	333.2	333.5	334.4	337.8	345.7	352.6	359.6	366.4	372.3	383.0	392.2
4TS	3+07.65D	308.5	331.6	331.8	330.4	328.5	328.3	330.7	338.4	346.3	354.3	361.6	368.0	380.0	390.0
5S	3+19.52D	304.0	331.4	331.8	332.0	331.7	334.0	336.1	343.8	350.1	358.2	364.9	370.9	381.7	390.9
Tuning Fork (Downstream)															
1	3+24.52D	296.0	331.4	332.9	336.3	342.0	347.9	351.4	357.9	363.7	369.4	374.8	379.7	388.0	396.1
2	3+32.52D	296.75	331.4	333.3	337.7	345.8	353.8	357.4	360.8	368.8	374.1	378.7	384.0	391.2	398.1
3	3+37.52D	305.0	331.4	334.0	341.2	352.8	367.4	372.3	377.7	380.9	384.0	387.6	390.8	396.6	401.2
Floor Culvert (Left)															
4U	2+01.00D	303.0	331.1	332.3	335.1	339.9	344.8	348.0	354.8	360.9	367.1	372.8	378.0	387.0	395.2
5U	1+13.50D	303.0	330.6	332.0	337.7	345.3	354.8	359.7	365.4	370.4	375.4	380.0	385.0	392.2	398.7
6U	0+38.50D	303.0	330.1	332.0	341.2	347.7	359.3	364.7	370.0	374.7	379.2	385.0	387.1	394.0	399.9
4D	3+62.00D	303.0	331.0	331.1	335.1	338.3	342.2	346.0	352.8	359.4	365.6	370.6	377.0	387.2	394.8
5D	4+49.50D	303.0	330.4	331.8	337.0	345.0	354.0	359.1	365.6	370.6	375.4	380.0	382.5	391.6	398.4
6D	5+24.50D	303.0	330.1	331.0	334.8	342.7	352.6	359.1	367.3	372.6	377.0	381.6	385.6	392.6	398.9
Floor Culvert (Right)															
4U	2+01.00D	303.0	330.7	331.6	333.9	337.3	340.9	344.6	352.4	358.6	365.0	370.8	376.1	387.6	393.9
5U	1+13.50D	303.0	330.5	331.8	336.3	345.6	356.0	361.8	368.2	372.9	377.7	381.7	385.7	392.6	399.0
4D	3+62.00D	303.0	330.7	331.8	333.8	337.0	341.2	344.5	351.7	358.0	364.4	370.7	376.0	387.6	394.2
5D	4+49.50D	303.0	331.0	331.4	335.0	341.9	350.8	356.2	363.6	368.8	373.9	378.7	386.7	391.0	397.7

Note: Elevations are in feet referred to mean sea level. 1-min valve fills lock in 10.3 min.
Bulkhead slots and air vents below filling valves closed.

* T is time (in prototype seconds) after beginning of filling operation.

** LC is elevation of water surface in lock chamber.

T = 420 LC = 400.8	T = 480 LC = 406.4	T = 540 LC = 410.6	T = 600 LC = 413.5	T = 660 LC = 414.7
412.0	413.0	413.7	414.0	414.3
412.4	413.2	413.8	414.1	414.3
411.7	412.9	413.6	414.0	414.3
410.9	412.3	413.3	413.8	414.3
410.9	412.3	413.3	413.9	414.3
410.4	412.1	413.1	413.8	414.3
409.6	411.7	413.0	413.8	414.3
409.9	411.8	413.0	413.8	414.3
409.3	411.6	412.9	413.8	414.3
409.1	411.4	412.9	413.8	414.3
411.8	413.0	413.7	414.0	414.3
411.2	412.7	413.4	414.0	414.3
410.9	412.4	413.3	413.9	414.3
410.6	412.2	413.2	413.9	414.3
410.0	412.0	413.1	413.8	414.3
409.7	411.8	413.0	413.8	414.3
409.4	411.6	412.9	413.8	414.3
409.0	411.3	412.8	413.7	414.3
406.7	409.9	412.1	413.6	414.3
404.7	408.7	411.5	413.1	414.1
403.0	407.8	410.9	412.9	414.0
403.9	408.4	411.3	413.0	414.1
404.8	408.9	411.6	413.2	414.1
403.7	408.2	411.4	413.4	414.5
403.9	408.6	411.5	413.4	414.5
404.8	408.9	411.8	413.7	414.6
404.9	408.9	411.9	413.7	414.7
404.7	408.8	411.7	413.6	414.6
404.8	408.9	411.8	413.7	414.8
404.8	408.9	411.8	413.7	414.8
403.6	407.9	410.9	413.0	414.1
404.2	408.5	411.0	413.0	414.7
404.0	408.4	411.4	413.6	414.7
404.1	408.5	411.6	413.7	414.8
404.1	408.4	411.6	413.6	414.8
404.0	408.2	411.4	413.5	414.7
404.0	408.2	411.4	413.5	414.8
404.1	408.4	411.4	413.6	414.8
403.9	408.1	411.4	413.6	414.7
403.8	408.0	411.4	413.5	414.7
403.6	407.9	411.3	413.5	414.7
404.0	408.3	411.5	413.5	414.7
402.3	408.4	411.6	413.6	414.8
404.3	408.4	411.7	413.6	414.7
411.4	412.9	414.0	414.6	415.0
397.0	403.9	409.1	412.7	414.6
398.4	404.9	409.6	412.9	414.6
399.7	405.6	410.2	413.2	414.8
398.0	404.7	409.7	412.9	414.8
398.7	404.7	409.6	412.8	414.7
402.0	407.0	410.8	413.4	414.8
403.6	407.9	411.3	413.6	414.9
405.8	409.2	412.0	413.8	414.8
401.6	406.9	410.9	413.5	414.9
403.9	408.2	411.6	413.8	415.0
404.6	408.6	411.8	413.9	415.1
401.3	406.4	410.5	413.4	414.9
403.9	408.0	411.6	413.8	415.0
404.0	408.0	411.5	413.7	415.0
400.9	406.1	410.5	413.2	414.6
404.0	408.1	411.4	413.7	415.0
400.9	406.2	410.5	413.2	414.8
403.2	407.8	411.3	413.6	414.9

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Table A3

Average Piezometer Readings During Filling, Type 18 Arrangement, 84

Upper Pool El 414.0, Lower Pool El 330.0, Single (Left) 1-Min Valve

Piezometer Locations			Average Piezometer Readings in Prototype Fe												
No.	Station	Elevation	T = 15* LC = 330.3**	T = 30 LC = 330.8	T = 45 LC = 332.0	T = 60 LC = 333.3	T = 75 LC = 335.5	T = 90 LC = 337.7	T = 105 LC = 339.7	T = 120 LC = 341.7	T = 150 LC = 345.7	T = 180 LC = 349.7	T = 240 LC = 357.2	T = 300 LC = 364.0	T LC
Intake (Left Wall)															
1	2+76.36U	352.0	414.2	413.7	412.9	410.7	407.5	405.5	405.2	405.5	405.9	406.4	407.3	408.1	4
2	2+75.61U	352.0	414.2	413.7	412.9	410.8	406.2	407.0	407.2	407.2	407.7	407.9	408.0	409.4	4
3	2+62.36U	352.0	414.2	413.3	411.9	405.4	404.0	401.7	401.4	401.4	402.8	403.3	404.7	405.9	4
4	2+51.23U	352.0	414.2	412.8	410.9	405.9	399.5	396.5	396.6	396.9	397.9	398.6	400.0	402.5	4
5	2+39.11U	352.0	414.1	412.7	410.9	406.3	400.1	397.0	397.1	397.6	398.4	399.8	401.0	402.7	4
6	2+27.11U	352.0	414.0	412.4	410.3	405.0	398.4	394.5	394.3	394.8	395.8	396.8	399.0	400.8	4
7	2+14.61U	352.0	414.0	411.9	409.2	402.1	393.5	388.8	388.8	389.4	390.7	391.9	394.7	397.1	3
8	2+02.86U	352.0	413.9	411.6	409.0	401.7	393.6	390.0	390.2	390.8	392.0	393.2	335.8	398.0	4
9	1+90.61U	352.0	413.9	411.6	408.9	401.3	392.5	387.4	387.4	387.7	389.2	390.6	393.4	396.0	3
10	1+78.61U	352.0	413.9	411.1	408.1	400.0	390.9	386.0	386.2	387.1	388.3	389.8	392.8	395.6	3
11	2+63.61U	352.0	414.2	413.3	412.0	408.9	405.0	403.0	403.1	403.4	403.9	404.4	405.7	406.8	4
12	2+51.61U	352.0	414.1	413.0	411.5	407.5	402.5	399.7	399.7	400.0	400.8	401.6	403.0	404.4	4
13	2+39.11U	352.0	414.1	412.7	411.0	406.1	400.2	397.0	397.0	397.4	398.4	399.1	400.9	402.7	4
14	2+27.36U	352.0	414.0	412.3	410.2	404.6	397.9	374.5	394.7	395.3	396.2	397.2	394.2	401.1	4
15	2+14.86U	352.0	413.9	411.9	409.6	403.0	395.4	391.7	392.0	392.6	393.7	394.8	397.0	399.2	4
16	2+02.61U	352.0	413.9	411.7	409.0	401.9	393.5	389.5	389.7	390.4	391.7	392.8	395.4	397.7	39
17	1+90.36U	352.0	413.8	411.8	408.6	400.8	391.9	387.7	388.0	388.7	389.9	391.3	394.0	396.6	39
18	1+78.11U	352.0	413.7	410.9	407.7	398.8	388.8	382.0	383.0	385.2	386.7	388.0	391.2	394.1	39
19	1+52.11U	352.0	413.4	409.2	404.0	390.3	375.8	318.7	369.0	370.3	372.6	374.8	379.4	384.0	38
Culvert Drop Section (Left Wall)															
1	1+29.11U	352.0	413.8	410.6	404.5	392.9	375.0	363.7	362.0	363.1	365.9	368.8	373.9	379.2	38
2	1+17.40U	350.0	413.7	409.8	402.6	388.8	368.8	355.5	353.0	354.2	357.6	360.8	366.9	373.1	37
3	1+05.70U	347.3	413.6	409.4	402.3	389.6	370.0	358.7	357.7	359.1	362.0	365.2	370.8	376.5	38
4	1+00.70U	345.2	413.6	409.5	403.3	391.2	374.2	364.1	363.2	364.4	367.0	349.7	374.8	379.9	38
5	0+34.0D	312.0	412.0	405.0	396.4	380.0	360.8	353.0	353.6	355.2	358.4	361.8	367.7	373.7	37
6	0+39.0D	312.0	412.0	405.0	396.1	380.9	362.3	354.4	355.6	357.3	360.2	363.6	369.3	375.0	37
Filling Valve (Left Wall)															
1	0+58.0D	298.0	409.9	403.6	396.0	377.1	359.2	355.0	355.9	357.7	360.6	363.5	369.3	375.1	38
2	0+58.0D	305.0	409.7	403.7	395.7	378.2	360.4	354.7	355.8	357.5	360.4	363.3	369.1	374.9	37
3	0+58.0D	312.0	410.7	404.0	397.1	379.9	360.5	354.8	355.8	357.6	360.5	363.8	369.1	374.9	37
4	0+58.0D	305.0	410.2	403.6	396.3	378.6	360.7	355.1	356.0	357.8	360.7	363.6	369.4	375.2	38
5	0+68.0D	312.0	409.9	403.4	395.3	375.5	357.5	354.4	355.6	357.1	360.0	363.0	368.9	374.8	37
6	1+00.00D	312.0	428.2	313.2	303.1	309.1	336.9	348.1	349.6	351.3	354.9	358.3	365.6	372.6	377
7	1+10.00D	312.0	427.9	312.9	302.7	309.0	342.9	350.8	352.0	353.9	357.1	360.1	366.5	372.6	377
8	1+21.50D	312.0	328.4	313.9	304.4	314.0	345.9	349.8	351.0	353.0	356.3	354.8	365.8	372.0	377
9	1+26.50D	312.0	329.3	315.0	307.4	321.3	347.6	349.7	351.1	353.1	350.3	354.4	365.8	372.0	377
10	1+31.50D	298.0	330.9	318.7	314.0	326.3	348.1	350.8	352.1	354.0	357.1	360.1	366.4	372.6	377
11	1+31.50D	305.0	330.7	317.0	312.7	323.5	346.2	350.4	351.6	353.6	356.7	359.7	366.0	372.2	377
12	1+31.50D	312.0	330.8	316.1	311.8	325.2	348.0	349.4	350.9	352.9	356.1	359.1	365.7	372.0	377
13	1+31.50D	305.0	329.9	316.1	313.1	325.5	348.6	350.4	351.8	353.8	356.8	359.9	366.2	372.4	377
14	1+41.50D	312.0	332.9	321.0	319.0	331.8	347.2	348.7	350.3	352.1	355.6	358.4	364.9	371.2	376
15	1+71.50D	312.0	333.4	333.6	332.4	338.7	345.7	347.7	349.0	351.0	354.3	350.5	364.0	370.6	376
16	1+99.00D	312.0	332.8	335.1	336.7	340.6	344.7	346.7	348.1	350.2	353.6	356.6	363.3	369.8	375
Transition to Crossover (Left Wall)															
1	2+13.48D	312.0	333.1	335.8	337.8	343.0	347.3	349.4	350.8	352.9	356.0	359.0	365.5	371.7	377
2	2+40.98D	312.0	332.3	335.1	337.4	342.9	348.3	351.5	352.9	354.9	357.9	361.0	367.0	373.0	378
3	2+40.98D	296.0	332.0	334.8	337.7	343.5	348.7	351.6	353.2	355.0	358.1	361.0	367.2	373.2	378
Crossover Culvert															
1S	2+43.48D	304.0	331.9	336.4	344.8	363.2	382.7	392.0	395.9	397.0	398.0	399.0	401.0	403.9	404
2TS	2+55.35D	308.5	331.4	331.9	330.0	325.5	320.4	316.0	314.2	315.1	318.0	322.3	332.6	342.9	352
2BS	2+55.35D	299.5	331.5	332.3	330.0	324.6	315.8	312.8	314.4	317.1	322.2	327.0	337.3	347.2	356
3BS	2+55.35D	299.5	330.7	330.6	329.5	326.4	321.5	319.8	322.0	324.6	329.4	333.5	342.9	352.0	359
4TS	3+07.65D	308.5	330.6	330.3	327.7	322.3	318.5	312.6	313.7	316.4	321.8	326.6	336.6	346.2	354
5S	3+19.52D	304.0	330.5	331.0	330.8	330.0	329.0	329.0	331.3	334.1	330.1	341.4	350.1	357.8	365
Tuning Fork (Downstream)															
1	3+24.52D	296.0	330.4	330.8	330.6	329.7	329.0	328.9	329.9	332.1	336.4	340.6	348.8	357.2	364
2	3+32.52D	296.75	330.5	330.8	330.7	330.1	329.0	329.0	330.3	332.4	336.9	340.7	349.5	357.5	364
3	3+37.52D	305.0	330.4	332.1	335.9	344.4	354.0	362.9	364.9	366.0	368.9	370.9	375.8	380.0	384
Floor Culvert (Left)															
4U	2+01.00D	303.0	330.3	330.9	331.0	331.3	331.3	332.5	334.4	336.6	341.0	344.4	352.9	360.2	367
5U	1+13.50D	303.0	330.0	330.6	331.4	333.1	335.5	338.0	340.0	342.2	345.9	349.6	356.9	363.8	369
6U	0+38.50D	303.0	330.0	330.5	331.3	333.1	335.7	338.5	340.8	342.9	346.6	350.1	357.4	364.3	370
4D	3+62.00D	303.0	330.9	330.9	331.0	331.2	331.8	333.0	334.8	337.0	341.1	345.0	353.0	360.8	367
5D	4+49.50D	303.0	330.0	330.7	331.3	333.0	335.0	333.0	339.3	341.4	345.2	348.9	356.3	363.5	369
6D	5+24.50D	303.0	329.9	330.2	330.9	332.1	334.0	336.4	338.4	340.6	344.3	348.0	355.6	362.8	369
Floor Culvert (Right)															
4U	2+01.00D	303.0	330.2	331.0	330.9	330.3	328.9	329.0	330.9	333.3	337.1	340.6	349.0	357.6	364
5U	1+13.50D	303.0	330.0	330.7	331.8	334.7	339.1	343.0	345.4	347.5	350.9	354.3	361.1	367.8	373
4D	3+62.00D	303.0	330.0	330.9	331.3	331.9	330.8	334.0	335.3	337.6	341.9	345.5	353.3	360.7	367
5D	4+49.50D	303.0	330.0	330.8	331.5	333.7	337.0	340.8	343.4	345.7	349.3	352.9	360.0	366.7	372

Note: Elevations are in feet referred to mean sea level. 1-min valve fills lock in 19.6 min.
Bulkhead slots and air vents below filling valves closed.

* T is time (in prototype seconds) after beginning of filling operation.

** LC is elevation of water surface in lock chamber.

AD-A063 267 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 13/13
FILLING AND EMPTYING SYSTEM FOR BAY SPRINGS LOCK, TENNESSEE-TOM--ETC(U)
NOV 78 J H ABLES

UNCLASSIFIED WES-TR-H-78-19 NL

2 OF 2

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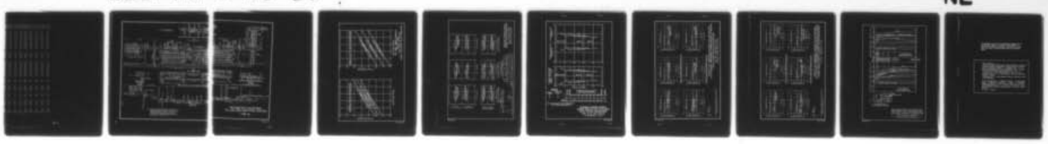
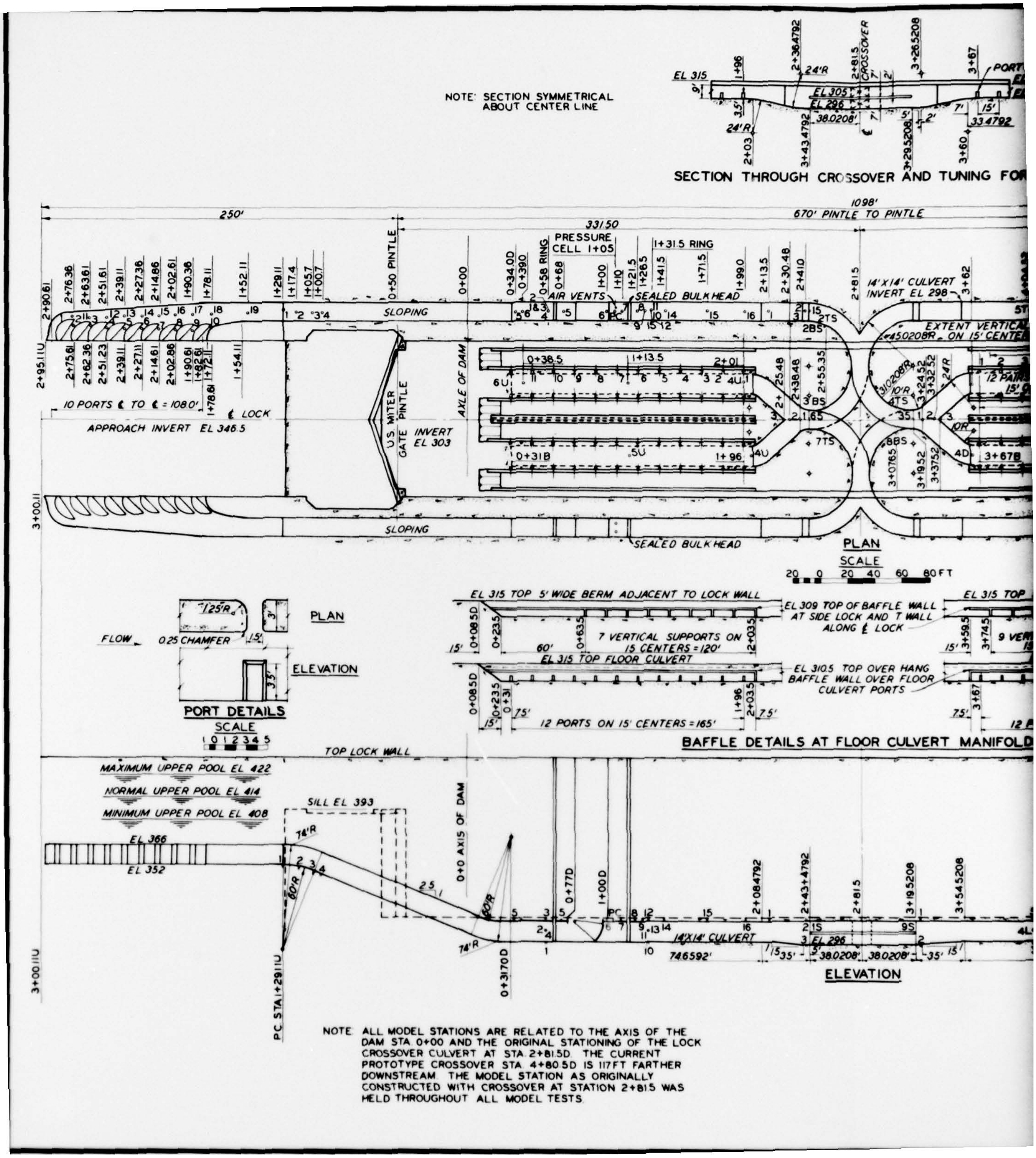
A063267

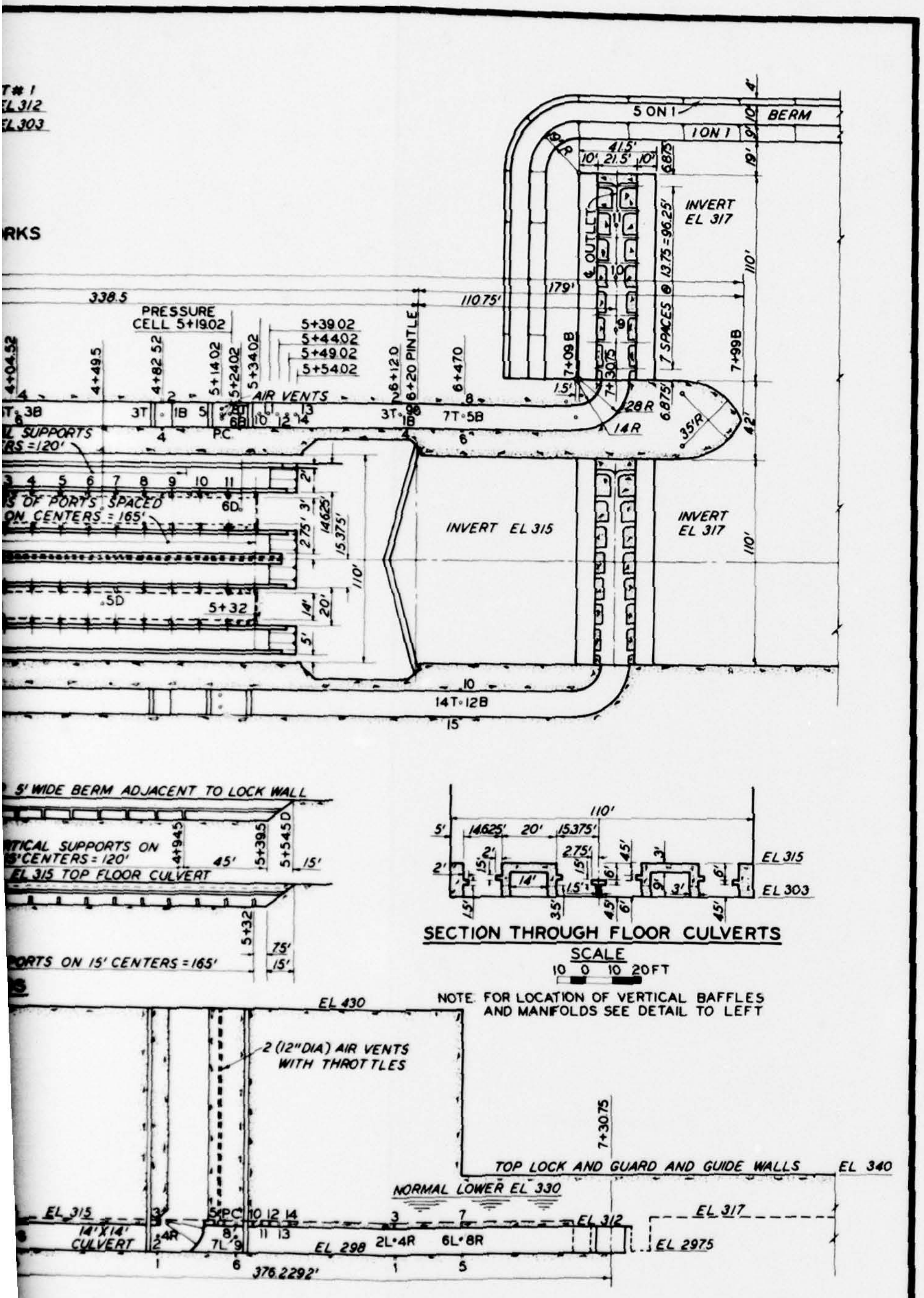


END
DATE
FILMED
3--79
DDC

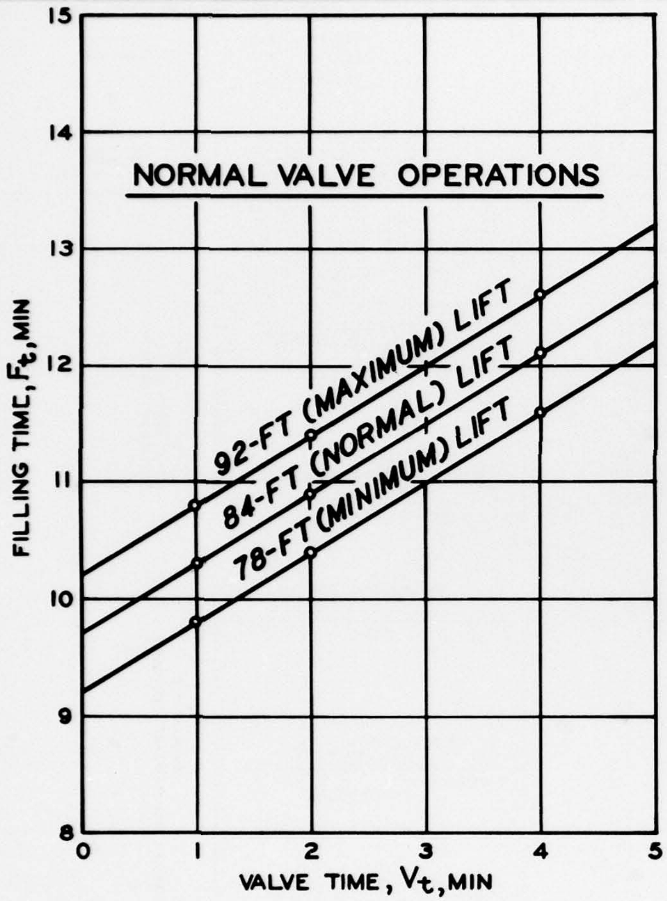
420 376.3	T = 480 LC = 381.7	T = 540 LC = 386.9	T = 600 LC = 391.7	T = 660 LC = 395.7	T = 720 LC = 399.5	T = 840 LC = 405.8	T = 960 LC = 410.2	T = 1080 LC = 413.3
.6	410.3	410.9	411.5	411.9	412.5	413.1	413.7	414.0
.6	411.0	411.6	411.9	412.4	412.9	413.3	413.8	414.0
.9	408.9	409.7	410.4	411.0	411.9	412.8	413.5	414.0
.1	406.4	407.8	408.3	409.8	410.9	412.0	413.1	413.9
.4	406.7	407.9	408.9	409.9	410.9	412.1	413.1	413.9
.9	405.5	406.9	408.0	409.3	410.5	411.9	413.0	413.8
.0	403.0	404.8	406.4	407.9	409.4	411.2	412.8	413.7
.0	403.8	405.6	407.0	408.3	409.6	411.5	412.9	413.7
.3	402.4	404.8	406.0	407.5	409.1	411.0	412.7	413.7
.0	402.0	403.9	405.0	407.2	408.9	410.9	412.6	413.7
.6	409.3	410.1	410.8	411.4	412.0	412.9	413.6	414.0
.8	407.9	408.9	409.8	410.6	411.5	412.6	413.3	414.0
.5	406.8	407.9	408.9	409.9	410.9	412.1	413.1	413.9
.3	405.8	407.0	408.2	409.3	410.6	411.9	413.0	413.9
.8	404.4	406.0	407.4	408.7	409.9	411.6	412.9	413.8
.7	403.6	405.2	406.8	408.0	409.6	411.4	412.8	413.8
.8	402.7	404.6	406.1	407.7	409.7	411.2	412.7	413.7
.9	401.1	403.2	405.0	406.8	408.6	410.8	413.5	413.7
.1	394.7	397.0	400.4	403.0	408.7	409.0	411.6	413.3
.2	391.6	395.1	398.4	401.3	403.6	408.0	411.3	413.1
.5	387.6	391.8	395.7	399.0	401.7	406.9	410.7	412.9
.3	389.8	393.7	397.1	400.2	402.7	407.6	411.0	413.0
.9	392.0	395.6	398.7	401.6	403.8	408.2	411.2	413.1
.0	387.9	393.1	395.9	399.3	401.9	407.1	410.9	413.1
.2	388.0	392.9	396.4	399.7	402.3	407.4	411.0	413.1
.3	388.7	392.8	396.2	399.7	403.0	407.4	410.8	413.1
.2	388.7	392.9	396.2	399.8	403.1	407.6	410.9	413.1
.2	388.6	392.7	396.1	399.6	403.0	407.3	410.8	413.1
.3	388.6	392.9	396.3	399.7	403.1	407.5	410.9	413.1
.2	388.2	392.3	395.8	399.0	402.7	406.9	410.3	412.8
.6	386.0	389.8	393.7	397.2	400.9	405.8	409.2	411.9
.4	387.9	391.3	395.0	398.7	402.3	406.9	410.6	413.0
.0	386.3	391.0	394.8	398.4	402.1	406.8	410.5	413.0
.3	386.7	391.1	394.9	398.5	402.3	406.9	410.6	413.0
.5	387.0	391.3	395.0	398.6	402.3	406.9	410.6	413.0
.3	387.5	391.1	394.9	398.5	402.2	406.0	410.6	413.0
.4	387.8	390.9	394.7	398.3	402.0	406.9	410.6	413.0
.2	386.9	391.2	394.9	398.6	402.3	406.9	410.6	413.0
.6	386.1	390.7	394.5	398.0	401.9	406.8	410.6	413.0
.9	385.7	390.4	394.2	397.9	401.8	406.7	410.5	413.0
.4	385.3	389.9	393.9	397.7	401.6	406.6	410.5	413.0
.3	386.7	390.9	394.8	398.1	402.0	406.8	410.3	412.9
.0	387.0	391.6	395.1	398.7	402.3	406.9	410.5	412.9
.2	387.0	391.7	395.4	398.9	402.6	407.0	410.5	412.9
.6	407.1	408.3	408.7	410.0	411.1	412.1	413.3	414.1
.6	367.7	375.2	381.7	387.5	394.1	401.9	407.9	411.9
.5	371.0	378.0	384.0	389.2	395.4	402.6	408.2	412.0
.7	373.7	390.1	385.7	390.8	396.4	403.1	408.6	412.3
.2	369.6	376.7	383.6	388.5	394.6	402.0	407.9	412.0
.4	377.6	382.5	387.3	392.8	397.6	403.9	408.8	412.2
.7	377.0	384.5	387.6	392.7	397.4	403.9	408.9	412.3
.0	377.0	383.5	387.6	392.8	397.7	403.9	409.0	412.3
.5	391.8	395.1	398.8	401.3	404.4	408.0	410.9	412.9
.1	378.9	384.0	389.3	393.9	398.7	404.6	409.3	412.5
.7	381.1	386.5	391.1	395.6	399.8	405.4	409.7	412.7
.1	381.3	386.8	390.9	395.1	399.6	405.6	409.4	412.7
.4	379.1	385.1	389.3	393.9	398.7	404.7	409.2	412.6
5	381.0	386.1	390.4	394.9	399.3	405.0	409.6	412.8
8	380.4	380.6	390.1	394.6	399.0	404.7	409.3	412.5
0	377.5	383.5	387.9	393.9	397.9	404.2	409.0	412.3
6	383.5	388.5	392.6	396.4	400.7	405.8	409.8	412.8
6	379.5	384.5	389.4	393.9	398.7	404.6	409.2	412.4
0	384.0	387.9	392.1	396.2	400.5	405.6	409.7	412.7

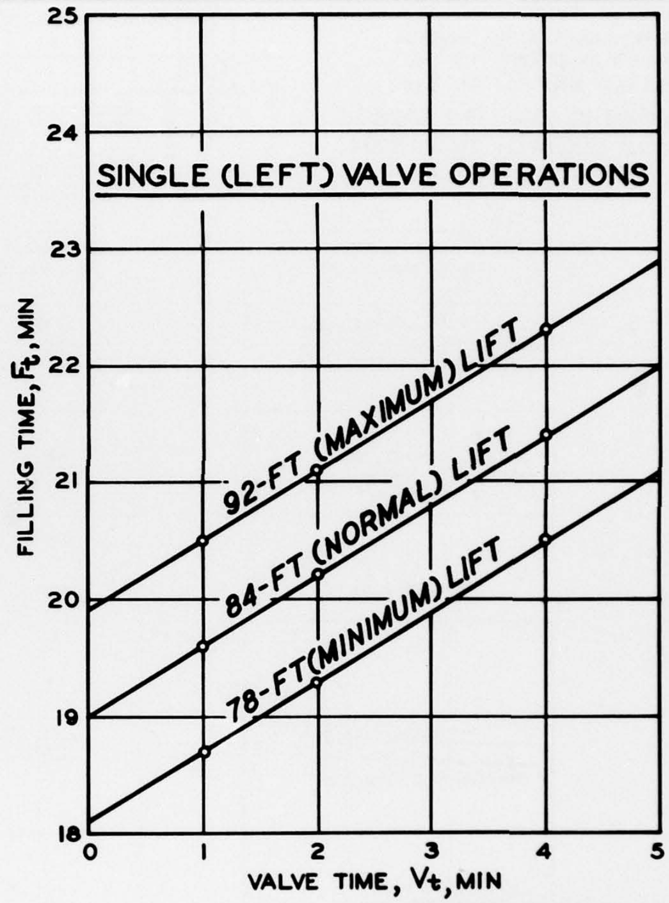
2


NOTE: SECTION SYMMETRICAL ABOUT CENTER LINE
SECTION THROUGH CROSSOVER AND TUNING FOR
PLAN
SCALE
20 0 20 40 60 80 FT
PORT DETAILS
SCALE
0 1 2 3 4 5
BAFFLE DETAILS AT FLOOR CULVERT MANIFOLD
ELEVATION
TOP LOCK WALL
MAXIMUM UPPER POOL EL 422
NORMAL UPPER POOL EL 414
MINIMUM UPPER POOL EL 408
SILL EL 393
EL 366
EL 352
APPROACH INVERT EL 346.5
10 PORTS ℄ TO ℄ = 108.0'
℄ LOCK
U.S. MITER GATE PINTLE
INVERT EL 303
AXLE OF DAM
SLOPING
SEALED BULKHEAD
AIR VENTS
PRESSURE CELL 1+05
14'X14' CULVERT INVERT EL 298
EL 315 TOP 5' WIDE BERM ADJACENT TO LOCK WALL
EL 309 TOP OF BAFFLE WALL AT SIDE LOCK AND T WALL ALONG ℄ LOCK
7 VERTICAL SUPPORTS ON 15 CENTERS = 120'
EL 315 TOP FLOOR CULVERT
EL 310.5 TOP OVER HANG BAFFLE WALL OVER FLOOR CULVERT PORTS
12 PORTS ON 15' CENTERS = 165'
NOTE: ALL MODEL STATIONS ARE RELATED TO THE AXIS OF THE DAM STA 0+00 AND THE ORIGINAL STATIONING OF THE LOCK CROSSOVER CULVERT AT STA 2+81.5D. THE CURRENT PROTOTYPE CROSSOVER STA 4+80.5D IS 117 FT FARTHER DOWNSTREAM. THE MODEL STATION AS ORIGINALLY CONSTRUCTED WITH CROSSOVER AT STATION 2+81.5 WAS HELD THROUGHOUT ALL MODEL TESTS.



PIEZOMETER LOCATIONS
FILLING AND EMPTYING SYSTEM
TYPE 18

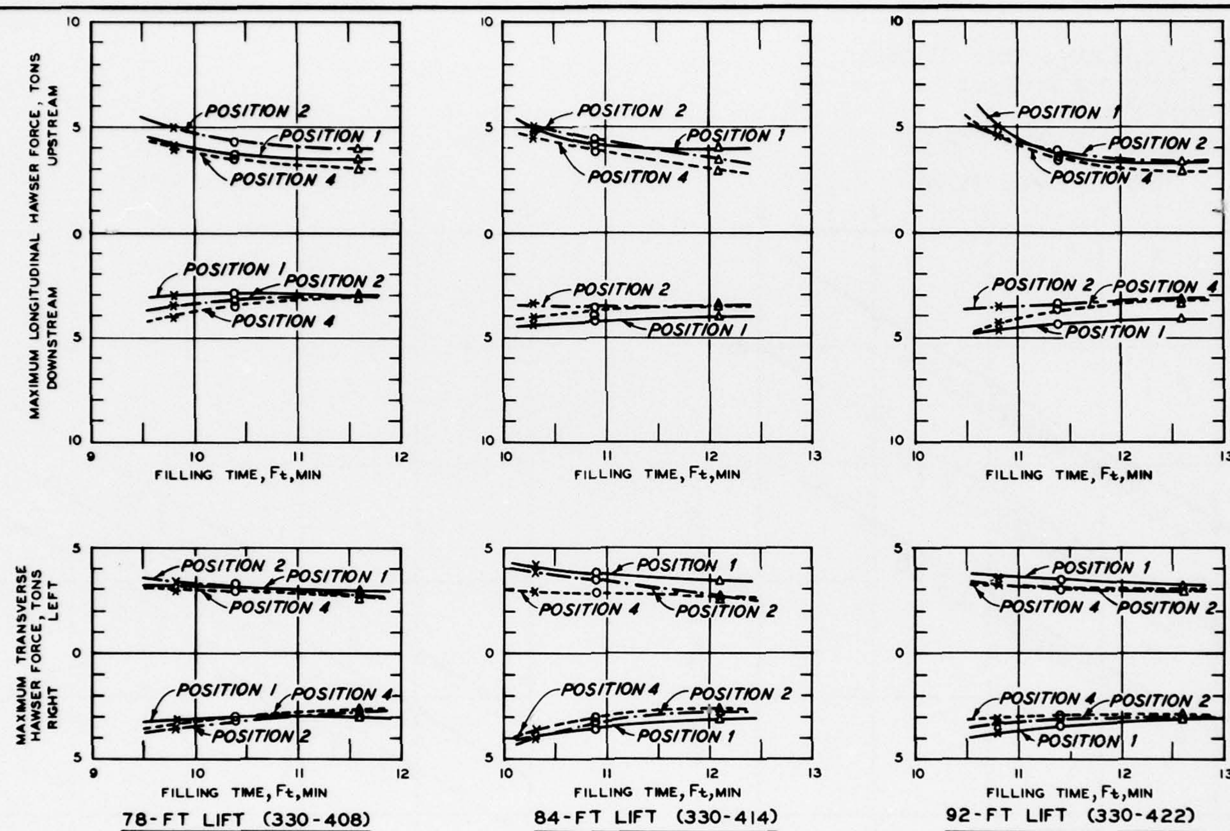




FILLING TIMES VERSUS VALVE TIME

TYPE 18 FILLING SYSTEM

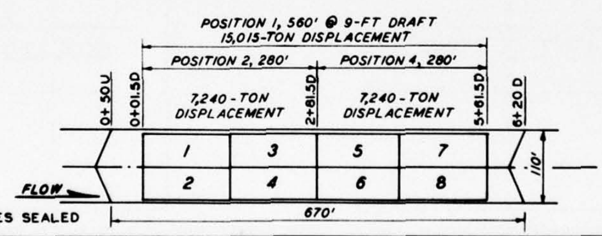
NORMAL AND SINGLE VALVE OPERATIONS



LEGEND

SYMBOL	VALVE TIME MIN	NO. OF BARGES	BOW STA	TOW POSITION NO.
x	1			
o	2			
Δ	4			
———		8	0+01.5D	1
—·—		4	0+01.5D	2
-----		4	2+81.5D	4

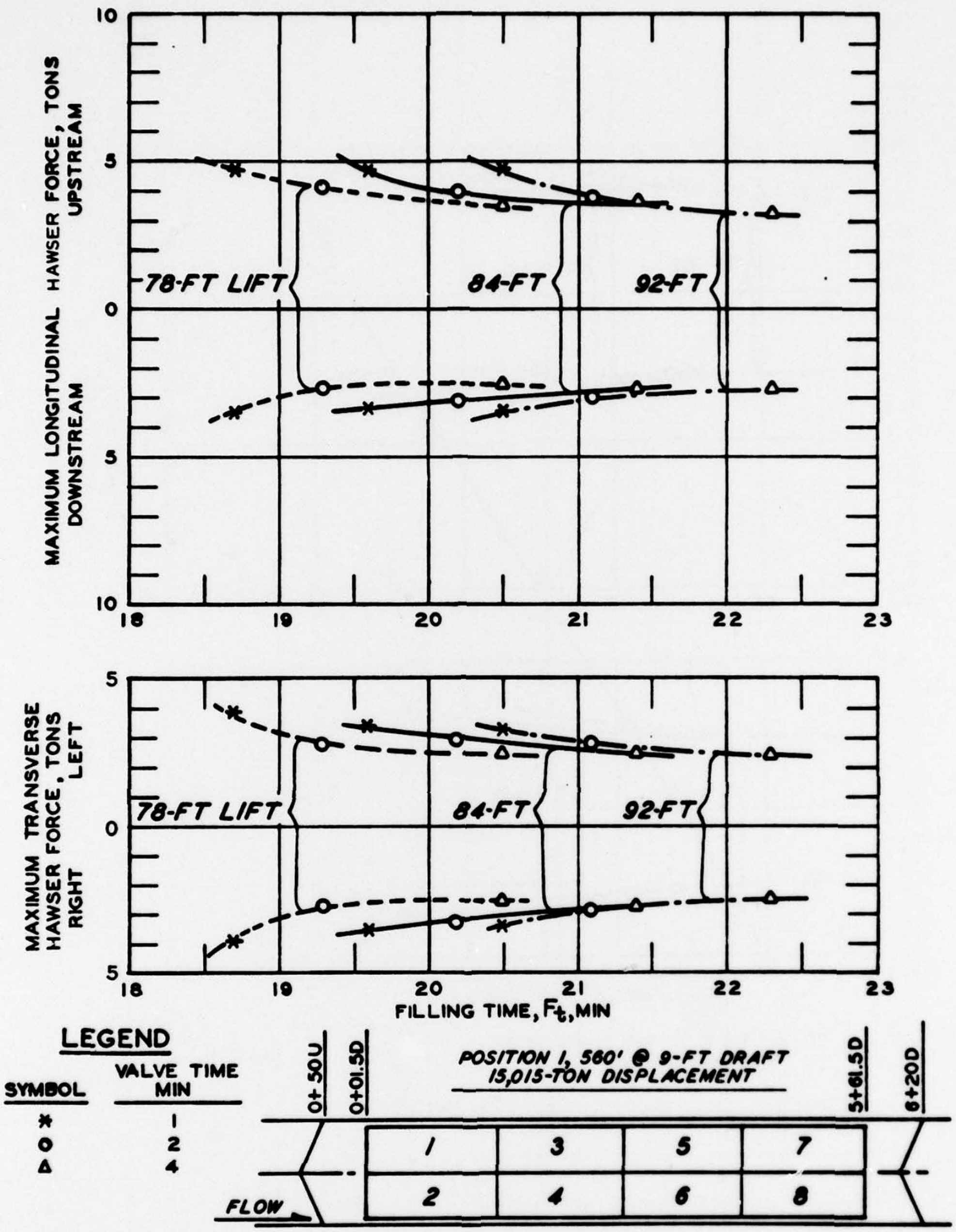
NOTE: BULKHEAD SLOTS DOWNSTREAM OF FILLING VALVES SEALED



MAXIMUM HAWSER FORCES DURING FILLING OPERATIONS

TYPE 18 FILLING SYSTEM

78-, 84-, AND 92-FT LIFTS
NORMAL VALVE OPERATIONS

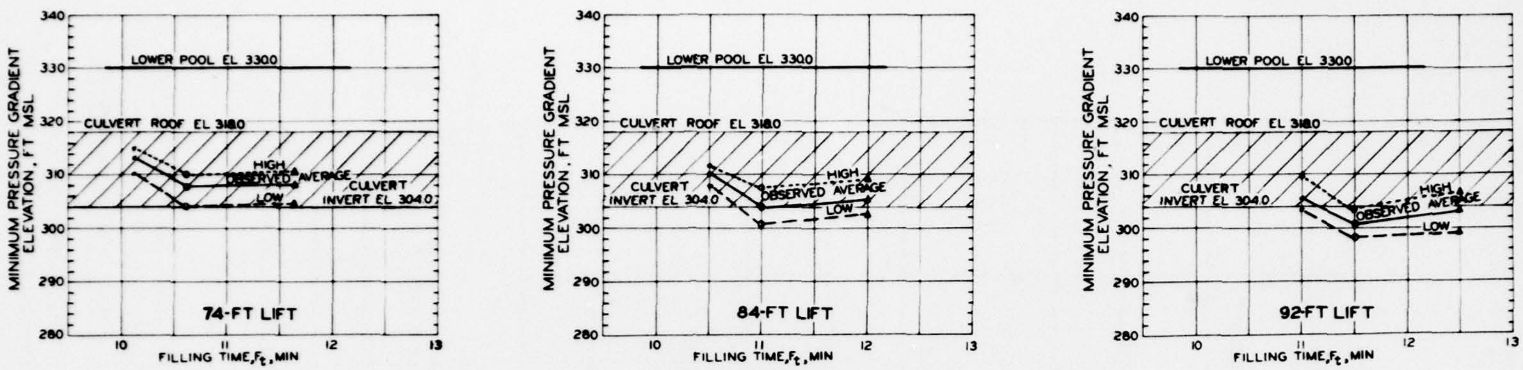


NOTE: BULKHEAD SLOTS DOWNSTREAM OF FILLING VALVES SEALED.

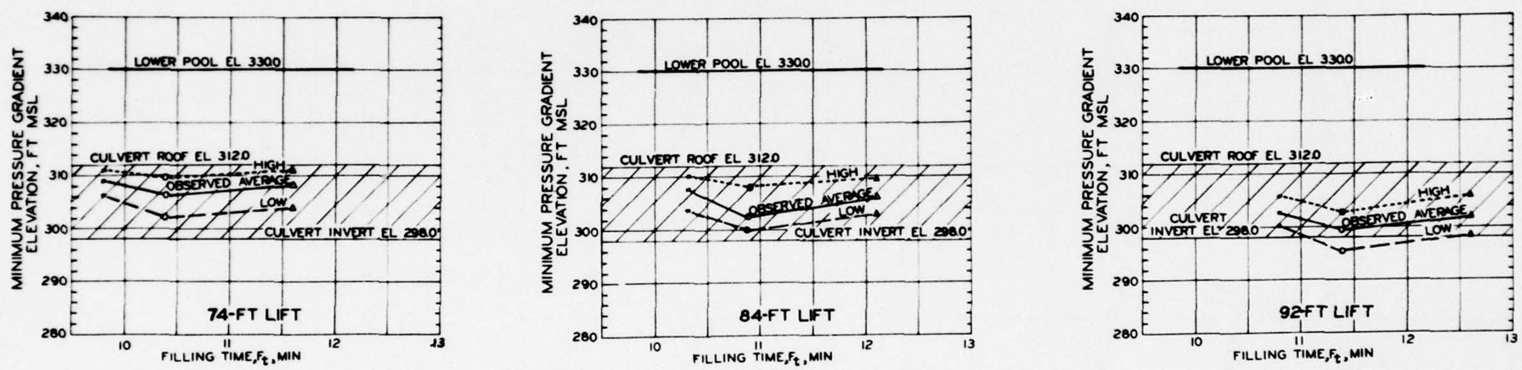
MAXIMUM HAWSER FORCES DURING SINGLE (LEFT) CULVERT VALVE FILLING OPERATIONS

TYPE 18 FILLING SYSTEM

78-, 84-, AND 92-FT LIFTS



TYPE 17 CULVERT VALVE ROOF AT EL 318



TYPE 18 CULVERT VALVE ROOF AT EL 312

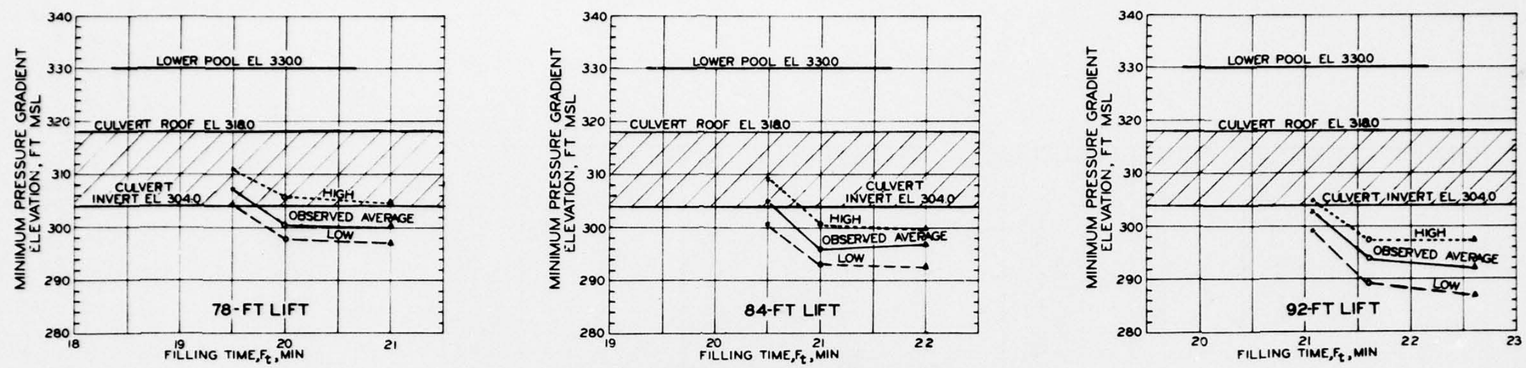
LEGEND

SYMBOL	VALVE TIME, MIN
*	1
O	2
Δ	4

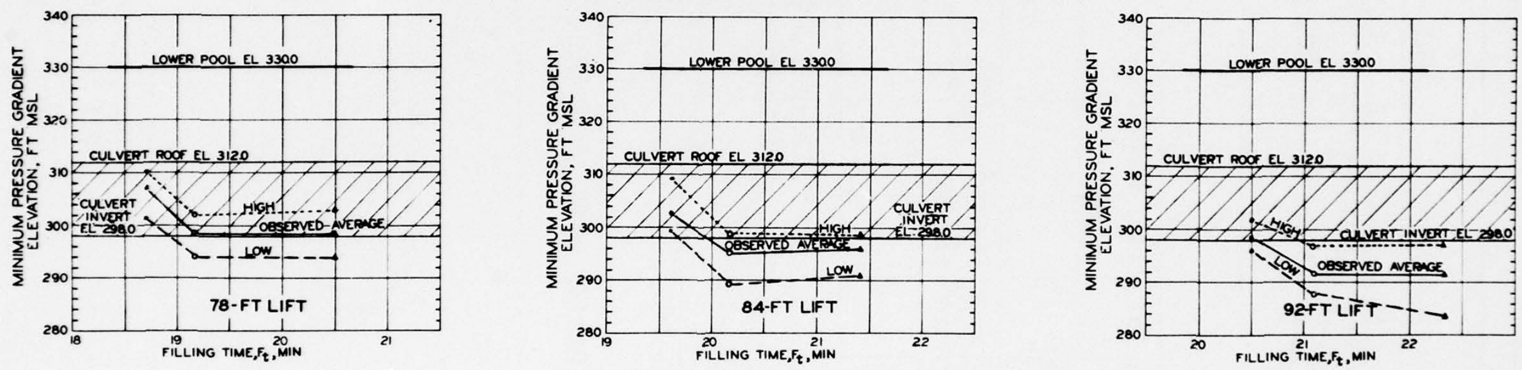
NOTE: BULKHEAD SLOTS DOWNSTREAM OF FILLING VALVES SEALED. PRESSURE CELL POSITIONED 7 FT DOWNSTREAM OF VALVE ON CENTER LINE OF CULVERT ROOF.

EFFECT OF LOWERING CULVERT FILLING VALVES
6 FT ON ROOF PRESSURES DOWNSTREAM OF VALVES
TYPES 17 AND 18 FILLING SYSTEMS
74-, 84-, AND 92-FT LIFTS
NORMAL VALVE OPERATIONS

PLATE A5



TYPE 17 CULVERT VALVE ROOF AT EL 318



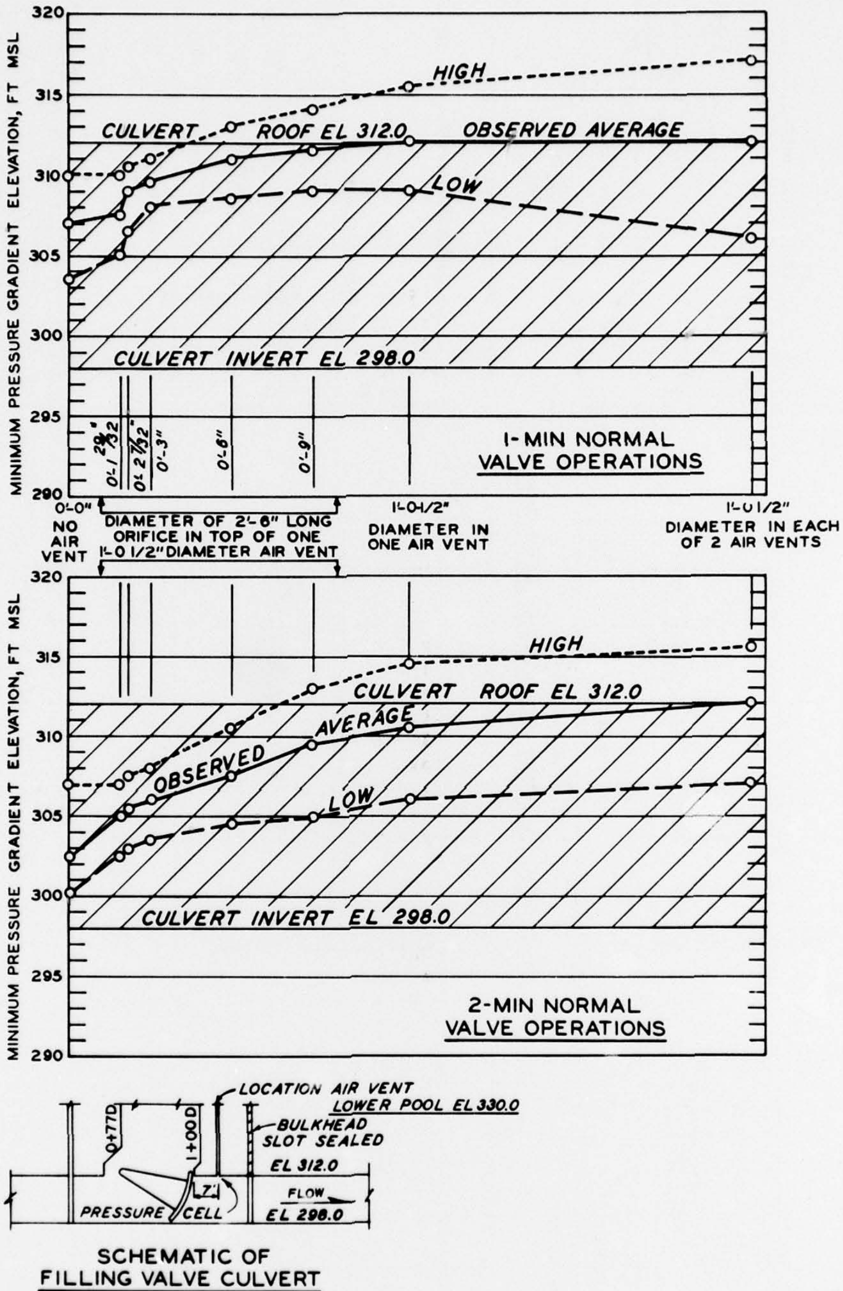
TYPE 18 CULVERT VALVE ROOF AT EL 312

LEGEND

SYMBOL	VALVE TIME, MIN
*	1
o	2
Δ	4

NOTE: BULKHEAD SLOTS DOWNSTREAM OF FILLING VALVES SEALED. PRESSURE CELL POSITIONED 7 FT DOWNSTREAM OF VALVE ON CENTER LINE OF CULVERT ROOF.

EFFECT OF LOWERING CULVERT FILLING VALVES
6 FT ON ROOF PRESSURES DOWNSTREAM OF VALVES
DURING SINGLE (LEFT) CULVERT VALVE OPERATIONS
78-, 84-, AND 92-FT LIFTS



QUALITATIVE EFFECT OF AIR VENTING ON CULVERT ROOF PRESSURES DOWNSTREAM OF CULVERT FILLING VALVES
TYPE 18 FILLING SYSTEM
84-FT LIFT (UPPER POOL EL 414.0 – LOWER POOL EL 330.0)
1- AND 2-MIN NORMAL VALVE OPERATIONS

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Ables, Jackson H

Filling and emptying system for Bay Springs Lock, Tennessee-Tombigbee Waterway, Mississippi; hydraulic model investigation / by Jackson H. Ables, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

27, [24], 3 p., [35] leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; H-78-19)

Prepared for U. S. Army Engineer District, Nashville, Nashville, Tennessee.

1. Bay Springs Canal. 2. Hydraulic models. 3. Locks (Waterways). 4. Navigation conditions. 5. Surges. 6. Tennessee-Tombigbee Waterway. I. United States. Army. Corps of Engineers. Nashville District. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; H-78-19.

TA7.W34 no.H-78-19